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ELEVENTH CONFERENCE on SOUTHERN FOREST TREE IMPROVEMENT

JUNE 15-16, 1971
QUALITY MOTEL
Atlanta, Georgia

sponsored by

Southern Forest Tree Improvement Committee

PROCEEDINGS OF THE
ELEVENTH CONFERENCE ON
SOUTHERN FOREST TREE IMPROVEMENT

ATLANTA, GEORGIA   JUNE 15-16, 1971

Sponsored publication No. 33
of the
SOUTHERN FOREST TREE IMPROVEMENT COMMITTEE
EASTERN TREE SEED LABORATORY
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in cooperation with
SOUTHEASTERN AREA, STATE AND PRIVATE FORESTRY and
Region 8, U. S. Forest Service.

Conference Chairman: Thomas F. Swofford

Conference Program Chairman: LeRoy Jones

Moderators: LeRoy Jones, Kingsley Taft,
Walter Beers, Jr.,
Thomas F. Swofford

Officers of SFTI Committee:

Chairman : Kingsley Taft
Vice Chairman: Eyvind Thor
Secretary : R. L. Koenig

The eleventh Southern Forest Tree Improvement Conference produced 38 papers covering a variety of topics on insect and disease resistance, genetics, and orchard management for both hardwoods and conifers.

As one reviews the papers it is evident that genetics is a tool of tree improvement and that tree improvement is a phase of forestry that is as important to the forest land manager as silviculture, soils, science and other disciplines in making his management decisions.

The papers contained herein were printed as submitted by the authors. The program committee made no attempt to edit the proceedings.

Region 8 and Southeastern Area, State and Private Forestry, U. S. Forest Service; and the Southern Forest Tree Improvement Committee cooperated in publishing the proceedings.

LeRoy Jones
Program Chairman
Southern Forest Tree
Improvement Committee

Erwin G. Wiesehuegel

Erwin G. Wiesehuegel ("Wiese") was a charter member of the Southern Forest Tree Improvement Committee and these Proceedings are dedicated to him. His passing has removed from the scene one of the early and strong supporters of tree improvement in American forestry.

His beginnings were in LaCrosse, Wisconsin. After a B.S. from the University of Michigan in 1922, he spent four years with the U. S. Forest Service in Wyoming and Utah, before going to the University of Idaho as an instructor. There he received the M.S. degree, and then spent a year as assistant professor. For a time, teaching at Ohio State University absorbed his talents, for he went there in 1930 as an assistant professor and, in turn, associate professor. But the major portion of his professional life was devoted to the Tennessee Valley Authority, where from 1936 to 1962 he had various responsibilities, including Branch Chief, Analysis and Planning Branch, Division of Forestry Development, at the time of his retirement. As Senior Forester in charge of forest resources and later as Chief, Forestry Investigations Branch, he gave guidance and strength to TVA's program in individual tree selection and in testing of improved nut trees and tree-crop species for open land planting.

At the First Southern Conference on Forest Tree Improvement in 1951, "Wiese" presented a paper on "Opportunities for Selecting Superior Phenotypes." In the Southern Forest Tree Improvement Committee, his participation was very active and resulted in his election to Chairman from 1957 to 1959. No assignment was too arduous and through his counsel and efforts many of the operational policies and subcommittee publications were developed. He was first Chairman of the Subcommittee on Progeny Testing, and through his efforts the Committee prepared sponsored publication No. 20 of the Southern Forest Tree Improvement Committee entitled, "Minimum Standards for Progeny Testing Southern Forest Trees for Seed Certification Purposes." He loved, and could become absorbed in, a constructive argument; insisted on preciseness in the Committee's public expressions; and, withal, evinced an infectious friendliness and good humor. I met and came to know Wiese in our association on the Committee and over the years increasingly valued his friendship and respected his sincerity and abilities.

His activities were not restricted to tree improvement. Wiese was elected an SAF Fellow in 1969. He was one of the main instigators and a charter member of the Kentucky-Tennessee Section of the SAF and served as Chairman in 1959. At the time of his death he was Chairman of the Section's Forestry Scholarship Fund which he was instrumental in establishing. And, as if this wasn't enough, he served the Boy Scouts of America for forty years and was recipient of the Silver Beaver Award.

As the spark of life fails in a friend, there is an initial sense of loss, but this is superseded by gratitude for having had the privilege of warm and rewarding association. It is in this sense that we here honor Wiese.

C. M. Kaufman

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WELCOME

Mr. Moderator, Ladies, and Gentlemen:

The opportunity to welcome you to Atlanta and this Conference is a source of great personal satisfaction. Regional Forester Ted Schlapfer had planned to greet you this morning but unfortunately had to be out of town today.

I hope you will have time to enjoy the many attractions of the Atlanta area while you are here. The Forest Service, as host, has attempted to do as complete a planning job as possible to insure the success of this conference. I hope you will let us know immediately if there is any way in which we can serve you. Our objective is to make this the smoothest-running conference to date. Both Tom Swofford, as General Chairman, and LeRoy Jones, as Program Chairman, are ready and willing to assist you with any problems you may encounter.

The importance of this meeting cannot be over-emphasized. This biennial conference may be credited in a large degree with elevating the Southern Genetic Tree Improvement Programs to their present level of National leadership. It provides communication among practitioners, scholars, researchers, and administrators. Here the latest state of the art of genetic tree improvement can be determined by all participants, thus insuring the use of the most advanced techniques and principles in day-to-day operations. Also, here the indications for direction of future research and experimentation are developed.

Research in the genetic improvement of forest trees started in this country 50-years ago. For decades these efforts were uncoordinated and meagerly supported, kept alive only by the dedication of a few individuals inspired by the progress abroad, especially in the Scandinavian countries.

Then, about 1950, the need for tree improvement became generally recognized, published results of earlier work encouraged further effort, and more trained workers and financial support became available. Examples of the results of earlier work were the seed source studies such as the 1911 ponderosa pine study in Northern Idaho, the 1916 Pike's Peak study, the 1912 Douglas fir study, and the 1926 loblolly study at Bogalusa, Louisiana. Research was broadened, intensified, and became better coordinated. Action programs took shape, especially in the South. A tremendous impetus to tree improvement resulted from the 1942 program at the

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Speech presented by R. M. Peterson, Deputy Regional Forester, U. S. Forest Service, at the Tree Improvement Conference at the Quality Hotel in Atlanta, Georgia, June 15, 1971.

Lake City, Florida Research Center in the intensive selection of high gum yielding slash and longleaf pine. This program demonstrated that the basic principles of inheritance hold good for Southern pines just as they do with agricultural crop plants.

From this beginning, the development of action plans mushroomed as evidenced by the following partial listing of events:

- 1949 - Calloway Tree Improvement Program initiated by Calloway Foundation and the Southeastern Forest Experiment Station.
- 1950 - TVA began agitating for the formation of a south-wide conference on tree improvement, resulting in the first meeting in 1951.
- 1951 - Texas Forest Service program initiated by Zobel.
- 1952 - Florida cooperative program initiated by Perry and Chi-Wu.
- 1952 - Crossett Company assisted Crossett Research Center of the Southern Station with financing.
- 1954 - Georgia Forestry Commission program started.
- 1954 - Southern Institute of Forest Genetics established.
- 1957 - North Carolina State College Cooperative formed by Zobel.

Since these dates, a host of agencies and individuals began active tree improvement programs. It is impossible to even list all participants, but among them are TVA, Westvaco, International Paper, Hodges, and our own Region 8.

If one had to specify the dominant tree improvement activity in the South in one sentence, he would have to describe it as the selection of superior trees within local races of species, the grafting of scions from those selections, and the establishment of the grafts in seed orchards. In short, the past and presently continuing major activities of Southern tree improvement are superior tree selection and seed production.

The production of seed from orchards is rapidly becoming more significant in Southern forestry. Some State nurseries now advertise the sale of superior seedlings. Many companies and organizations are using superior stock in stand regeneration. Orchards will become the principal source of supply for seed in the near future.

Tomorrow looks bright for Southern tree improvement. Progeny tests are proving the validity of superior tree selections. Second generation orchards are being planned and established. Techniques for seed collection and establishment of new forest stands are evolving. Intensive orchard selection programs and hybrid production are creating specialty trees for use in areas with unusual silvicultural requirements. The basis for tree improvement programs is changing from faith alone to demonstrated worth. We are also seeing more emphasis on finding superior trees for many purposes - urban beauty, noise buffers, wildlife habitat, etc.

Under the banner of tree improvement, industry, schools, TVA, State Forestry Departments and the Forest Service have joined hands to further the improvement of Southern forests. This cooperation has varied from the informal discussions that will take place among the participants of this conference, the activities of the Southern Forest Tree Improvement Committee, formal working agreements, to the formation and activation of tree improvement cooperatives. A free flow of information and maintenance of the desire to be helpful to others characterize Southern tree improvement. Such cooperation is real, effective, and outstanding. I'm sure it will continue.

I am not concerned about the probability of a good conference. All the elements of success are already present. Therefore, I will not express the wish for a successful meeting, but for an outstanding one.

Thank you.

NOW WE'RE GETTING SOMEWHERE

By

Thomas C. Nelson [1]

Good morning. Again welcome to the 11th Southern Forest Tree Improvement Conference. May I compliment you on the theme of this conference---it is most appropriate: NOW WE'RE GETTING SOMEWHERE! I can't hear that expression without thinking of the old farmer in Kansas who, after much soul-searching, spent $5,000 on a tornado shelter. After several years of no tornadoes, he was beginning to wonder if he had spent his money wisely. But one day the tornado warnings came and he placed himself and his family down in the shelter. After two hours, he climbed the steps, peeked out and beheld one of the worst scenes of destruction ever witnessed by man ---there was no barn, cattle were strewn throughout the countryside, his house was a shambles and most of his trees were uprooted.

"Well," he said, "now we're getting somewhere!"

Thankfully, we have a different reason for making that statement. Our long years of struggle with tree improvement are really beginning to pay off. In fact, it seems that dramatic results are piling up almost suddenly. It probably appears so to the outsider anyhow, but we know only too well that success has come to the tree improvement specialist like it did to Johnny Carson. He says it took 20 years for him to become an overnight sensation.

I have attended several of your tree improvement conferences in the the past but, now that you are overnight sensations, it is a particular pleasure to attend your eleventh meeting. I can remember, as I know you can, when tree improvement research was a modest undertaking, with only a few people climbing trees with little bags and stirring the curiosity of the entire countryside. In those days, their primary job was to select superior tree candidates and to make a few controlled pollinations to learn something about the heritability of tree characteristics. Fifteen years later, Keith Dorman's 1966 summary of Forest Tree Improvement Research in the South and Southeast listed 36 agencies and 305 projects not to mention the great number of people engaged in seed orchard development and tree evaluation work. Seed orchard development began about the same time as tree improvement research and, today, the production of improved seedlings is a reality. Many of them are from proven superior parents.

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[1] Associate Deputy Chief, State and Private Forestry, U. S. Forest Service

Think of it! The progeny of more than 10 clones in the South now show extreme resistance to fusiform rust, and the availability of rust-resistant seed from specialty orchards is just around the corner. Seven of these clones were proved out on the North Carolina State University cooperative project, involving Union Camp Corporation, U. S. Plywood-Champion Papers, Inc. and Continental Can Company. The economic impact of this development alone to forest operations in areas of high rust infection is astronomical.

Breakthroughs are occurring on many other fronts as well. We expect seed from high-gum-yield seed orchards to be available for planting within three or four years. Trees from this seed are expected to yield 25 to 100 percent more gum than ordinary trees.

Cottonwoods have been known as "instant trees" because of their superior growth characteristics; but now 14 superior clones have been developed by the Southern Hardwoods Laboratory at Stoneville, and we have run out of adjectives to describe the improved growth possibilities. Through the efforts of the Southeastern Area, State and Private Forestry, 600,000 cuttings will be made from these clones within the next year to meet the planting needs of industry and State nurseries for the production of superior planting stock.

Good news is also being heard from "Abraham," our old friend, the brown-spot-resistant longleaf at Alexandria, Louisiana. Abraham's offspring are rising above the grass in three years, leaving their less-fortunate cousins in the dust.

At the present time, there are over 5,800 acres of first generation Federal, State, and private forest tree seed orchards here in the South. This number is still increasing, even though second generation orchard establishment has started.

These first generation orchards can be managed for seed production well into the second generation production cycle. They can provide seed for domestic and export needs for many years, and it will be seed of good genetic quality.

More "Purpose Diversity" exists for these new orchards than was the case for the first generation orchards. Increased gum yield, low density, high density, disease resistant, high seed yield, high combining ability, fertilizer responsive, geographic area, and site responsive are some of the types of second generation orchards to be, or already under establishment.

We now have enough information to know that the genetic variability of many traits exists in the southern pines. Changes are possible in height, diameter, volume growth, wood quality, disease and insect resistance, stem form, branch morphology, drouth resistance and many other characteristics. Often the breeder's objective is to have a combination of these into one package, or strain. The challenge is amplified, however, when a thin base exists such as resistance to fusiform rust. While a broad base is desirable for the propagation of such trees, I believe we will be planting seedlings grown from the seed of two or three resistant clones in some areas.

At any rate, top management must consider genetics in their land management decisions if they are not already doing so. The assumptions for future practices and products are important to the tree improvement worker, for he must decide which traits are the most important. Culture practices? Silviculture treatments? Insect and disease control? Which ones? The genetics of trees is a part of management, and once the decision is reached the genes are fixed for the rotation.

Too, the systems analysis approach should receive more attention with input information on silviculture, harvesting, products desired and biological information coming from the scientists. When this is done, the values that the geneticists and other tree improvement disciplines associate with the various traits may change.

I can't stress enough the role cooperation has played in taking us this far. Almost every seed orchard program in the South has at least one cooperator. In addition to the three large industry-university cooperatives, I can name many organizations that have an agreement signed by two or three parties. In no other area of forestry is the association---and cooperation---of forest management and research personnel so close. All have worked together to develop seed orchards, collect research data and to guide scientists in developing their mission and objectives. Of course, it makes sense because tree improvement is a paying proposition. If forest tree genetics and tree improvement continue advancing, the next generation will realize gains that are hard to imagine.

Of course, there are limits to the extent of cooperation we can expect in the future, due to the expense involved in tree improvement work. Once the orchard is established, the cost has just really begun. It must continue to be managed, progeny must be tested and seed collected. Since much of the costs are fixed for an orchard, large or small, we may see a trend to larger orchards, or smaller orchards within working distance of each other.

The total estimated cost per year for State established and planned pine seed orchard programs in the South, on the basis of 200 selections per State, is $1,125,500. One million of this is for seed orchard maintenance, which includes seed collection. The cost will probably stay at approximately this figure for the next two to three years and then increase gradually until progeny tests are completed.

As the costs of tree improvement programs are large, I suggest that many of the private tree improvement programs now underway will give way to State-sponsored programs. Gains derived from both the public and the private sectors can be incorporated into State-operated programs. Seedling stock derived from these efforts will be available from State nursery programs for industrial and other private land planting work. Increased competence in both tree improvement work and nursery management will attend State program development, thus insuring continued gains in the quality of future forest tree planting stock.

Again....congratulations. I can't think of any other phase of forestry research that has grown so large so fast. No doubt, reports here during the next two days will annotate these accomplishments in detail. You will also be covering present projects and future plans. On this subject, I have only three points that I might add to your deliberations.

First, we must really work at keeping a broad genetic base in the seed orchards. Many of you will be the first to admit that the base of our first generation orchards could and should have been even broader. Second generation orchards must incorporate the best of the first generation orchards, plus new material. Although there are no hard and fast rules, our knowledge on incompatibilities and other problems suggests that new material should comprise 30 percent or more of the lines uses in the second generation orchards. For some types of orchards this percentage is much too low---perhaps 75 percent would be better.

Second, I would urge the continuation of seeking new plus tree candidates. To be sure, there is not the same sense of urgency to get these plus trees that you all experienced in establishing your first generation orchards. There is, nevertheless, an "Aura of Finality" associated with most tree stumps.' Their usefulness to future tree improvement work is very limited. As the harvest moves across the South again, we must be certain to save and incorporate - into our breeding collections - into our germ plasm banks - the best of the natural populations still available. Once gone, they are gone forever.

Third, some statement should be made about hardwood tree improvement. There is need for tremendous effort over the next 15 years for tree improvement efforts with a number of important southern hardwood species. These include sweetgum, sycamore, cottonwood, tulip-poplar, tupelo gum and cherry-bark oak. As yet there is no good substitute for time in forestry work; thus this time-consuming work must be carried out now to insure the gains we know we will need with hardwoods tomorrow.

And lastly, let's take pride as we move this improved stock into the forestation picture. Make a big thing of it publicly.

Today's emphasis on environmental enhancement, resource renewals, anti-pollution, sound abatement, and the need for expanded forest areas all cry out for your actions. The improved quality trees you are producing blend into that picture with such ease you must emphasize them as they appear. Let's continue to tell the public in a positive way about forest genetics and forest tree improvement. Here are two forestry activities that have, in a few short years, produced results destined to have a profound and continually increasing effect on tomorrow's total renewable forest resource.

We see now that our efforts on tree improvement started none too soon. Projections of supply and demand for wood products in the year 2000 lead to the conclusion that 55 percent of the Nation's wood and wood products must come from the South and this production must come from less acreage than is available for timber growing today. At one time, the year 2000 seemed a long way off, but I guess I'm getting older. It now seems to be imminent. It is particularly so to the tree improvement scientist because, in a manner of speaking, it is only a progeny test and a roguing operation away. More and more people feel that genetic improvement is potentially the most valuable technique available for increasing wood production. Remember when the genetic gain estimate of volume started out at about three percent? Now we hear figures of 10 percent and even as high as 19 percent as progeny test results begin coming in. What will be the results from second-generation seed orchards?

I can assure that your efforts are capturing the imagination of the forestry world. Keep up the good work. The eyes of the Nation are upon you!

TECHNICAL SESSIONS

Disease and Insect Resistance

Banquet speaker: Dr. Noah Langdale, President
Georgia State University

BREEDING PEST-RESISTANT FOREST TREES: DEVELOPMENTS AND TRENDS

Ronald J. Dinus[1]

A decade ago breeding for resistance was considered only a promising means of reducing losses to forest insects and diseases. Convincing examples have since demonstrated its practicality. These accomplishments have awakened regional, national, and international interest in resistance breeding. A review of contemporary efforts indicates that 35 breeding programs are well underway and that another 29 have been initiated recently (Gerhold 1970). Several older programs have released resistant planting stock and over half of those underway expect to do so within 10 years. A number of programs in the Southeast are in the latter category.

Unlike alternative methods of control, planting genetically resistant material can offer both economy and long-term effectiveness. These advantages plus widespread and increasing concern over the quality of our environment make it imperative that resistance breeding and research efforts be intensified.

This brief review describes some recent developments in pest resistance research and discusses their implications. Fusiform rust, caused by Cronartium fusiforme Hedgc. & Hunt ex Cumm., seriously threatens efficient management of loblolly (Pinus taeda L.) and slash pines (P. elliottii Engelm. var. elliottii). Since this disease is the concern of most papers in this session of the Eleventh Southern Conference on Forest Tree Improvement, much of this review will deal with resistance to fusiform rust.

SOURCES OF RESISTANCE

Inherent resistance to a variety of pests has been found in a number of forest tree species. Comprehensive reviews are available (Beck 1965; Bingham 1969; Ewing and Manning 1967; Gerhold 1970; Hare 1966; Toole 1966). Reference to and descriptions of specific programs may also be found in the published proceedings of two recent symposia (Bingham et al. 1971; Gerhold et al. 1966).

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[1] The author is Plant Geneticist at the Institute of Forest Genetics, Southern Forest Experiment Station, USDA Forest Service, Gulfport, Mississippi.

Developments and problems relevant to the Southeast are best illustrated by several examples. Information concerning the extent and usefulness of resistance to fusiform rust and brown-spot needle blight, caused by Scirrhia acicola (Dearn.) Siggers, has accumulated rapidly. Reports by Wells (1969) confirm earlier indications (Wells and Wakeley 1966) that losses to rust in loblolly pine can be reduced by reforesting with seed from an appropriate provenance. Damage to longleaf pine (P. palustris Mill.) by S. acicola can be diminished by the same means (Henry and Wells 1967). Though the degree of protection ultimately desired may not be achieved, the usefulness of geographic variation as an interim step should not be overlooked. Moreover, some resistance can be obtained without sacrificing other qualities. Further evidence of geographic variation in resistance to these diseases is provided in contributions to this meeting by Derr, and Wells and Switzer.

This approach holds little promise for improving the resistance of slash pine to C. fusiforme (Gansel et al. 1971). This does not imply, however, that useful levels of resistance are unavailable in this species. When geographic variation in resistance is not readily apparent, variation among individual trees can be sought and exploited. For example, resistance to C. ribicola Fischer has been found in western white pine (P. monticola Dougl.) by selecting disease-free phenotypes in heavily damaged stands (Bingham et al. 1969). Subsequent progeny tests under conditions favorable for disease development have yielded a usable number of parents with high general combining abilities.

Levels of resistance obtained by the selection of loblolly and slash plus-trees free of fusiform rust have not been impressive (Goddard and Strickland 1970; LaFarge and Kraus 1967; North Carolina State University 1970). At best, only moderate gain seems possible (Kinloch and Stonecypher 1969). Some of the uncertainty associated with phenotypic selection may be minimized by restricting the practice to young, heavily damaged plantations. In another contribution to this conference, the author has observed useful amounts of resistance in progenies of rust-free slash pines. The parents were chosen at age 13 from a 94-percent infected plantation and individual tree histories were known. Existing provenance and progeny test plantings in hazardous areas are therefore logical places to seek new sources of resistance. The survey of rust incidence recently begun by the State and Private

Forestry Branch of the USDA Forest Service and recent studies of rust epidemiology (Snow et al. 1968) should provide much needed information on the location and distribution of such sites. Both types of information should also contribute to the more efficient location and design of future test plantings.

The usefulness, if not necessity, of progeny testing for detecting resistance to fusiform rust has been demonstrated (Kinloch and Stonecypher 1969). Maximum increases in resistance are expected only after existing clonal orchards are rogued or new specialty orchards are established on the basis of progeny tests. Predicted and realized gains are compared by Blair and Zobel in a contribution to this meeting. Derr and Melder (1970) found substantial variation in resistance to brown-spot needle blight among individual longleaf pines. Their results and those of Snyder and Derr indicate, however, that progeny testing is required to identify useful parents with certainty. Approximately 10 percent of the 500 selections whose progenies have been examined at several locations may be suitable for eventual release.

When variation in resistance is lacking or minimal within species, resistance genes may be available in related species. Interspecific hybridization, backcrossing, and similar breeding methods can then be employed to transfer resistance into the susceptible species. Interspecific hybridization has resulted in increased resistance to *C. ribicola*, *Ceratocystis ulmi* (Buism.) C. Moreau, and *Keithia thujina* Durand (Wood 1966). Attempts to produce usable hybrids of *Castanea* species resistant to *Endothia parasitica* (Murr.) A. and A. are described in a contribution by Nichols and his associates.

The disease resistance of southern pine hybrids has also been studied extensively. Derr (1966) reported that longleaf x slash pine hybrids are less susceptible than their parents to brown-spot needle blight and fusiform rust, respectively. The long-term effectiveness of rust resistance in these hybrids has been questioned, however. Though among the more resistant entries in a south Mississippi planting after 5 years, the hybrids were as susceptible as slash pines at 10 years[2]. Interspecific hybrids of slash or loblolly and shortleaf pines (*P. echinata* Mill.) have considerable resistance to fusiform rust (Schmitt 1968), but the usefulness of individual shortleaf parents can vary (Jewell 1966). The apparent necessity to select suitable parents in both species introduces a significant complication.

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[2] Schmitt, D. M. Personal communication.

The considerable expense presently associated with mass-producing hybrid and backcross seed also limits the efficiency of this approach. Nevertheless, such hybrids could find practical use in the future and will continue to be valuable for studying the genetics and mechanisms of resistance.

METHODS OF EVALUATING RESISTANCE

Concern over the efficiency and reliability of progeny testing for resistance to plant pathogens in the field is widespread. The uncertainties associated with the year of planting, the amount and distribution of inoculum, and the effects of site and cultural conditions have been discussed frequently. The length of time required to obtain a satisfactory incidence of infection also represents a major shortcoming. Moreover, plantings which reliably test for resistance may prove of limited utility for evaluating other traits. A paper contributed by Schmidt and Goddard suggests that consistency of family performance is obtained only when the overall incidence of rust is moderate to high.

Artificial inoculation methods have often been adopted as alternatives or supplements to field testing. Successful procedures for evaluating resistance to a substantial number of major fungal diseases have been devised. The objectives, methodology, and advantages of these were discussed at two recent symposia (Gerhold et al. 1966; Bingham et al. 1971).

Several artificial inoculation methods are often available for investigating a particular host/pathogen combination. Some attempt to simulate natural conditions. Others are performed in the field, but modify conditions to enhance the probability of infection. Still others utilize tents, sheds, greenhouses, or specialized chambers. In most successful methods, large numbers of young trees (30 days to 4 years old) are exposed to heavy, uniform concentrations of inoculum under conditions favorable to disease development. Provision for replication in time and space are routine. Schmidt (1971) has reviewed procedures for evaluating resistance to fusiform rust.

Several resistance-breeding agencies employ a series of artificial inoculations (Patton and Riker 1966; Heybroek 1969). That is, seedlings remaining disease-free after the first exposure are tested again in one or more subsequent seasons. Repeated exposure minimizes the frequency of escapes, thereby providing a reservoir of useful plant material. In addition, the accuracy of calculations concerning genetic ratios or the extent of additive genetic variation is increased. Unfortunately, personnel concerned with resistance to fusiform rust have not attempted reinoculation on a large scale, but provisions for both repeated inoculations and preservation of rust-free material have been made recently at the University of Florida and the Southern Station. Results from two successive inoculations of slash pine with C. fusiforme are described in a paper contributed by Goddard and Schmidt.

Most techniques currently used for mass screening provide only for heavy and uniform exposure to composite collections of local inoculum. Experience with crop plants shows, however, that interactions between host genotypes and inoculum densities or sources can affect the performance of individual varieties or cultivars. It may be misleading, therefore, to consider two pine selections equally useful when progeny from one are 25 percent galled after light exposure while progeny from the other are similarly infected following a massive dose. Several agencies active in fusiform rust research have recognized this problem. Work in progress suggests that differences in the amount of rust among open-pollinated progenies of slash pine decrease with increasing inoculum densities (Snow and Dinus, unpublished data). A report contributed by Powers et al., however, indicates that differences among open-pollinated progenies of loblolly pine can be distinguished at a number of different inoculum levels. Both studies noted a strong positive correlation between rust incidence and inoculum density.

The inoculation techniques employed in these studies of inoculum density represent major advances. Each has been described in detail at a recent symposium (Dwinell 1971; Snow and Kais 1971). Both can be adapted to study the interaction between inoculum source and host genotype. Such investigations have been initiated by Snow and Kais (1970). Progenies from susceptible slash and loblolly selections were uniformly infected by inoculum from five geographic sources. Slash pine progenies normally resistant to Mississippi inoculum were moderately resistant to three sources, but susceptible to the others. Since some degree of pathogenic variability was evident, progeny testing with mixed collections of inoculum from the particular area to be reforested was advised. Further studies of the extent and nature of this variability are underway.

Though successful inoculations are now routine for a variety of forest diseases, knowledge of the infection process remains incomplete in many instances. Bingham (1969) emphasized the need for further information on the penetration and establishment of rusts on hard pines. At present, it is assumed that fusiform rust galls develop after penetration of the stem or of succulent tissues near the stem. Since resistance mechanisms may be operative in one or more of these places, the relative importance of each as a natural infection court must be clarified. A technique developed within the last year (Miller 1971) permits control not only of inoculum density and source, but also of the point of application. As a result, much-needed information on the mode of penetration of _C_. _fusiforme_ and infection courts may now be within reach.

Another advance of interest to tree improvement personnel in the Southeast is that toward successful inoculation of longleaf pines with spores of _S_. _acicola_. As illustrated in a contribution by Derr, much valuable information on the extent of heritable variation in resistance to brown-spot needle blight has been derived from conventional or modified field tests. The technique for controlled inoculation being developed by Kais at the Southern Station, however, should hasten and increase the efficiency of testing.

Not all inoculation techniques will make practical contributions to tree improvement. The more specialized types should provide greater insight into resistance mechanisms. The impact of those designed for mass screening, however, will be minimal unless their results accurately predict field performance. The blister rust program in Idaho has been based since its inception on the assumption that family rankings after nursery inoculation will be similar to those in forest plantations. Recent surveys tend to support this assumption. After exposure for 11 and 15 years in hazardous areas, progenies of parents selected for high general combining ability outperformed both control and wild seedlings (Steinhoff, manuscript in preparation).

To date, only three reports have been published concerning the relationship between artificial and field tests for fusiform rust (Dinus 1969; Gansel et al. 1971; Kinloch 1968). Further data will be given at this conference by Goddard and Schmidt. Though agreement was considered reasonable in two instances, the available methods do not seem to predict field performance with the desired degree of accuracy.

Both the failure to identify resistant selections and the identification of a susceptible selection as resistant can have serious consequences (Schmidt 1971). With rotation lengths commonly approaching or exceeding 25 years, the effects of the latter are perhaps more severe. Incorrect classification of useful parents may be less serious in that breeders could obtain sufficient usable parents by screening progenies from large numbers of selections. On the other hand, exposing young seedlings to heavy inoculum loads may be eliminating selections whose progeny express resistance only when older or in the field (Dinus 1969). Hence, breeders might be biased toward relying on a single form of resistance, possibly a form more easily overcome by the pathogen.

These problems demand immediate attention. Future mass screening studies should be designed to parallel existing or proposed field trials. Should current systems need refinement, provisions should be made for standardization of conditions, especially inoculum viability, density, and dispersal. Optimum densities, that is, densities which permit genetic differences to be expressed but minimize the frequency of escapes, must be found. Results might also be more realistic if slightly older seedlings were used. Moreover, new methods of quantifying host response deserve further investigation.

The techniques of Dwinell and Snow could prove useful for large-scale screening. Since both provide considerable control over the more troublesome variables, modifications of them are being considered for use at a central testing facility to be operated by the State and Private Forestry Branch of the USDA Forest Service. Though much work remains undone, this facility, located at Asheville, North Carolina, is preparing to begin preliminary testing. When it is fully operational, standardized testing services will be available on a regional basis.

Evaluating resistance to insect attack is also difficult, but increased demand for resistant material in recent years has quickened the pace of research. The resultant fund of knowledge has been summarized by Gerhold (1966). The enormous and perplexing variations in the location, frequency, and severity of natural attacks make field identification and evaluation of resistance difficult, if not impossible. Callaham (1966) has discussed the problems associated with field testing and emphasized the need for perfecting reliable cage tests, attractants, and bioassays. Such methods have succeeded in several instances (Gerhold 1970).

Methods for forcing attacks by Dendroctonus species on western yellow pines have been developed by Smith (1969). Both the quality and quantity of resin were related to the levels of resistance possessed by individual host trees. Bioassays suggested that certain components of the resin confer resistance by the lethal effects of their vapors. Two monoterpenes, limonene and 3-carene, have been implicated. Similar approaches are being employed in studies of resistance to a number of related insects, including the southern pine beetle (Dendroctonus frontalis Zimm.).

Screening caged white pine (P. strobus L.) seedlings for resistance to white pine weevils (Pissodes strobi (Peck)) has also proven feasible (Soles et al. 1969). The technique has been used to distinguish among resistant and susceptible species, provenances, and individual host trees. The information accumulated is considered sufficient to justify the start of a practical program of selection and breeding.

The anticipated development of controlled testing procedures, however, should not prevent the thorough observation of natural infestations. Observations made during attacks in progeny tests, provenance plantings, and seed orchards are especially valuable. For the present, such opportunities may be the only means of determining if and to what extent inherent resistance to some insects exists. Much to the advantage of all concerned, several reports of variation in susceptibility under such circumstances will be given at this meeting.

LONG-TERM EFFECTIVENESS

Tree improvement workers continue to express the concern that pests may eventually overcome resistance. The risk associated with existing pathogenic variability or that produced in response to the planting of resistant material is not easily determined. Bingham (1969) has emphasized the pressing need for increased attention to this problem.

Until recently, most resistance research programs have concentrated on calculating heritabilities and estimating gains. Though sufficient variation in host resistance and reasonable potential for gain have often been found, little is known about the number and nature of the underlying genes. Will collecting these genes into improved progeny result in long-term control of pests currently possessing or capable of producting pathogenic variability?

The experience of crop breeders, particularly those concerned with improving resistance in wheat and potatoes, could easily lead to pessimistic predictions. On the average, wheat varieties resistant to specific races of the wheat rust pathogen remain useful for only a few growing seasons (Borlaug 1965). The differential resistance used in these instances is based on only one or a few genes with large effects (van der Plank 1969). On the other hand, maize breeders have developed less spectacular, but longer-lasting resistance (Hooker 1967) by seeking uniform rather than differential resistance. This approach provides protection against a spectrum of pathogenic races. Apparently, large numbers of genes with small, additive effects are involved (van der Plank 1969). In view of the rotation lengths common in forestry, the consequences of intentionally or unintentionally developing differential resistance could be severe. Trees might not be harvestable, as wheat and potatoes sometimes are, before an induced change in pathogenicity assumes significance.

If resistant progeny are to be planted with confidence, the genetics of both resistance and pathogenicity must be understood. The reactions comprising the overall levels of resistance usually observed must be characterized and the responsible gene or genes identified. For example, a number of genes controlling resistance to blister rust have been found in western white pine (Hoff and McDonald 1971). Two genes control reactions in secondary needles, another controls needle lesion frequency, a fourth controls the premature shedding of infected needles, and a fifth controls a fungicidal reaction in the short shoot. The existence of others governing reactions in both foliage and bark has been postulated. Resistance apparently controlled by a single dominant gene has also been observed in _P. lambertiana_ Dougl. (Kinloch et al. 1970). The nature of the reaction, however, has not been determined. The classification of genes in this manner and continued exposure of plants containing them should clarify the contribution of each to long-lasting resistance.

Knowledge of host genetics, however intimate, is not sufficient. Existing and potential variation in pathogenicity must also be defined. The mechanisms providing for genetic change in many important fungal parasites of forest trees are not clearly understood. Evidence for variation in characteristics other than pathogenicity is extensive (Wood 1966). Reports of pathogenic variation are fewer, but information is accumulating (Wood 1966; Bingham 1969). Recently, evidence was found for the existence of two pathogenic races of *C. ribicola* with corresponding differential resistance genes in *P. monticola* (Hoff and McDonald 1971). Moreover, clear indications of pathogenic variability have been found in *C. fusiforme* (Snow and Kais 1970).

Most tree species are more heterozygous than the crops in which problems with differential resistance have arisen. Moreover, uniform resistance seems more prevalent in crops which have been subjected to lesser degrees of artificial selection (Graham and Hodgson 1965). Hence, problems such as those experienced with wheat may not, or need not, befall tree breeders. Until adequate information becomes available, however, an intensified search for uniform resistance seems the safest course. Bingham (1969) suggested that criteria such as fewer galls per tree (LaFarge and Kraus 1967) and slower gall development (Kinloch and Kelman 1965) may prove helpful in programs concerned with fusiform rust.

COMMUNICATION AND COOPERATION

Increased interest in pest-resistant forest trees has intensified the need for effective communication and cooperation among geneticists, pathologists, entomologists, and physiologists. The benefits resulting from a freer exchange of information, sharing of biological materials, and instigation of cooperative studies seem obvious. Various organizations have recognized these and resolved to facilitate communication and cooperation.

Several specialized workshops and symposia have been held in response to past resolutions. An Advanced Study Institute of Genetic Improvement for Disease and Insect Resistance of Forest Trees was held in 1964 at the Pennsylvania State University and a similar symposium, the Advanced Study Institute on Biology and International Aspects of Rust Resistance in Forest Trees, was held in 1969 at Moscow, Idaho. A session of the Second World Consultation on Forest Tree Breeding in 1969 at Washington, D.C., also provided for contact among resistance breeders. In addition, committees concerned with resistance to conifer rusts have been formed within the framework of the IUFRO Working Group on Genetic Resistance to Forest Insects and Disease.

The combined efforts of interested parties resulted in an informal workshop on fusiform rust in 1970 at Bainbridge, Georgia. Informal as it was, this conference provided an effective forum for reviewing progress, identifying the most pressing problems, and discussing new approaches. Considerable concern was expressed over the availability of standard inoculum sources and seed from proven resistant and susceptible selections. As a result, depositories providing for the storage and exchange of aeciospores and seed have been established at North Carolina State University and Macon, Georgia, respectively. In addition, initial steps were taken toward obtaining support for the creation of a central rust resistance testing facility. Though loosely organized at present, the original attendees and other interested individuals could easily become a more vital force. The necessary machinery could perhaps be furnished by the IUFRO Working Group with its White Pine Blister Rust Resistance Committee serving as model. This latter group organized the highly effective Advanced Study Institute in 1969.

If existing and prospective means of communication and cooperation are to be effective, increased financial and administrative support is essential. The training value of a particular meeting might be the most meaningful criterion for attendance. Research administrators should not only be made aware of relevant professional and working meetings, but also of any realized as well as potential benefits of attendance. The merits of individual visits and additional education cannot be overemphasized. Unfortunately, funds and approval for such activities are especially difficult to obtain. Research administrators should periodically review and endeavor to fulfill these needs.

LITERATURE CITED

Beck, S. D. 1965. Resistance of plants to insects. Annu. Rev. Entomol. 10: 207-232.

Bingham, R. T. 1969. Rust resistance in conifers--present status, future needs, pp. 483-497. In Second World Consultation on Forest Tree Breeding. Vol. 1, Sect. 5, No. 2.

_______, Hoff, R. J., and McDonald, G. I. (eds.) 1971. Biology of rust resistance in forest trees. 681 pp. (In Press) Gordon and Breach, N.Y.

_______, Olson, R. J., Becker, W. A., and Marsden, M. A. 1969. Breeding blister rust resistant western white pine. V. Estimates of heritability, combining ability, and genetic advance based on tester matings. Silvae Genet. 18: 28-38.

Borlaug, N. E. 1965. Wheat, rust, and people. Phytopathology 55: 1088-1098.

Callaham, R. Z. 1966. Needs in developing forest trees resistant to insects, pp. 469-473. In H. D. Gerhold et al. (eds.) Breeding pest-resistant trees. Pergamon Press, N.Y.

Derr, H. J. 1966. Longleaf x slash hybrids at age 7: survival, growth, and disease susceptibility. J. For. 64: 236-239.

_______, and Melder, T. W. 1970. Brown-spot resistance in longleaf pine. Forest Sci. 16: 204-209.

Dinus, R. J. 1969. Testing slash pine for rust resistance in artificial and natural conditions. Tenth South. Forest Tree Improv. Conf. Proc. 1969: 98-106.

Dwinell, L. D. 1971. An inoculation system for Cronartium fusiforme, pp. 327-330. In R. T. Bingham et al. (eds.) Biology of rust resistance in forest trees. (In Press) Gordon and Breach, N.Y.

Ewing, A. W., and Manning, A. 1967. The evolution and genetics of insect behavior. Annu. Rev. Entomol. 12: 471-494.

Gansel, C. R., Brendemuehl, R. H., Jones, E. P., Jr., and McMinn, J. W. 1971. Seed source effects in 5- and 10-year-old test plantings of slash pine in Georgia and Florida. Forest Sci. 17: 23-30.

Gerhold, H. D. 1966. In quest of insect-resistant forest trees, pp. 305-318. In H. D. Gerhold et al. (eds.) Breeding pest-resistant trees. Pergamon Press, N.Y.

_______, 1970. A decade of progress in breeding disease-resistant forest trees. Unasylva 24: 37-44.

_______, Schreiner, E. J., McDermott, R. E., and Winieski, J. A. (eds.) 1966. Breeding pest-resistant trees. 505 pp. Pergamon Press, N.Y.

Goddard, R. E., and Strickland, R. K. 1970. Cooperative forest genetics research program, 12th progress report. Univ. of Fla. Sch. of For. Res. Rep. 18, 36 pp.

Graham, K. M., and Hodgson, W. A. 1965. Effect of major and minor gene interaction on adaptive parasitism in Phytophthora infestans. Phytopathology 55: 73-75.

Hare, R. C. 1966. Physiology of resistance to fungal diseases in plants. Bot. Rev. 32: 95-137.

Henry, B. W., and Wells, O. O. 1967. Variation in brown-spot infection of longleaf pine from several geographic sources. USDA Forest Serv. Res. Note SO-52, 4 pp. South. Forest Exp. Stn., New Orleans, La.

Heybroek, H. 1969. Three aspects of breeding trees for disease resistance. Second World Consultation on Forest Tree Breeding. Vol. 1, Sect. 5, No. 4, pp. 519-535.

Hoff, R. J., and McDonald, G. I. 1971. Stem rusts of conifers and the balance of nature, pp. 525-535. In R. T. Bingham et al. (eds.) Biology of rust resistance in forest trees. (In Press) Gordon and Breach, N.Y.

Hooker, A. L. 1967. The genetics and expression of resistance in plants to rusts of the genus *Puccinia*. Annu. Rev. Phytopathol. 5: 163-182.

Jewell, F. F. 1966. Inheritance of rust resistance in southern pines, pp. 107-109. In H. D. Gerhold et al. (eds.) Breeding pest-resistant trees. Pergamon Press, N.Y.

Kinloch, B. B., Jr. 1968. Genetic variation in susceptibility to fusiform rust in loblolly pine. Ph.D. Thesis. N.C. State Univ., Raleigh. 47 pp.

_______, and Kelman, A. 1965. Relative susceptibility to fusiform rust of progeny lines from rust-infected and noninfected loblolly pines. Plant Dis. Rep. 49: 872-874.

_______, and Stonecypher, R. W. 1969. Genetic variation in susceptibility to fusiform rust in seedlings from a wild population of loblolly pine. Phytopathology 59: 1246-1255.

_______, Parks, G. K., and Fowler, C. W. 1970. White pine blister rust: simply inherited resistance in sugar pine. Science 167: 193-195.

LaFarge, T., and Kraus, J. F. 1967. Fifth-year results of a slash pine polycross progeny test in Georgia. Ninth South. Forest Tree Improv. Conf. Proc. 1967: 86-91.

Miller, T. 1971. Inoculation of slash pine seedlings with stored basidiospores of *Cronartium fusiforme*. Phytopathology 60: 1773-1774.

Patton, R. F., and Riker, A. J. 1966. Lessons from nursery and field testing of eastern white pine selections and progenies for resistance to blister rust, pp. 403-414. In H. D. Gerhold et al. (eds.) Breeding pest-resistant trees. Pergamon Press, N.Y.

Schmidt, R. A. 1971. A literature review of inoculation techniques used in studies of fusiform rust, pp. 341-356. In R. T. Bingham et al. (eds.) Biology of rust resistance in forest trees. (In Press) Gordon and Breach, N.Y.

Schmitt, D. 1968. Performance of southern pine hybrids in south Mississippi. USDA Forest Serv. Res. Pap. SO-36, 15 pp. South. Forest Exp. Stn., New Orleans, La.

Smith, R. H. 1969. Xylem resin as a factor in the resistance of pines to forced attacks by bark beetles. Second World Consultation on Forest Tree Breeding. Vol. 1, Sect. 5, No. 6, pp. 537-553.

Snow, G. A., and Kais, A. G. 1970. Pathogenic variability in isolates of Cronartium fusiforme from five Southern States. Phytopathology 60: 1730-1731.

________, and ________, 1971. Technique for inoculating pine seedlings with Cronartium fusiforme, pp. 325-326. In R. T. Bingham et al. (eds.) Biology of rust resistance in forest trees. (In Press) Gordon and Breach, N.Y.

________, Froelich, R. C., and Popham, T. W. 1968. Weather conditions determining infection of slash pines by Cronartium fusiforme. Phytopathology 58: 1537-1540.

Soles, R. L., Gerhold, H. D., and Palpant, E. H. 1969. Testing white pine seedlings for weevil resistance. Second World Consultation on Forest Tree Breeding. Vol. 1, Sect. 5, No. 9, pp. 575-583.

Steinhoff, R. J. (MS in preparation.) Field levels of infection of first-generation progenies of western white pines selected for blister rust resistance. USDA Forest Serv. Intermt. Forest and Range Exp. Stn. Res. Note. Ogden, Utah.

Toole, E. R. 1966. Breeding for disease and insect resistance in hardwoods. Eight South. Forest Tree Improv. Conf. Proc. 1966: 20-24.

van der Plank, J. E. 1968. Disease resistance in plants. 206 pp. Acad. Press, N.Y.

van der Plank, J. E. 1969. Pathogenic races, host resistance, and an analysis of pathogenicity. Neth. J. Plant Pathol. 75: 45-52.

Wells, O. O. 1969. Results of the southwide seed source study through 1968-69. Tenth South. Forest Tree Improv. Conf. Proc. 1969: 117-129.

_______, and Wakeley, P. C. 1966. Geographic variation in survival, growth, and fusiform-rust infection of planted loblolly pine. Forest Sci. Monogr. 11, 40 pp.

Wood, F. A. 1966. The current status of basic knowledge of forest tree disease resistance research, pp. 293-300. In H. D. Gerhold et al. (eds.) Breeding pest-resistant trees. Pergamon Press, N.Y.

VARIATION IN RUST RESISTANCE IN MISSISSIPPI LOBLOLLY PINE

O. O. Wells and G. L. Switzer[1]

Abstract.--Stands with a high degree of resistance were located in the Florida parishes of Louisiana and southwestern Mississippi. Stands nearest the Gulf Coast in Alabama and Mississippi were least resistant, and resistance increased gradually to the north and west. There were more highly resistant stands along the western margin of the range in Mississippi than along the Mississippi-Alabama border. Attempts to correlate these results with the distribution of shortleaf pine (*Pinus echinata* Mill.) were only partially successful.

The among-stand effect was about nine times larger than the within-stand effect. Therefore, in development of resistant loblolly (*P. taeda* L.) strains for planting, first priority should be given to selection of geographic areas and stands.

Range-wide provenance tests have demonstrated that genetic resistance to southern fusiform rust (*Cronartium fusiforme* Hedgc. and Hunt ex Cumm.) exists in parts of the loblolly pine range, specifically (1) west of the Mississippi River, (2) in the Florida parishes of Louisiana (that part of Louisiana directly south of Mississippi and north of New Orleans), and (3) on the eastern shore of Maryland (Henry 1959, Wells and Wakeley 1966). In tests over a smaller geographic area Crow (1964) has found genetic variation in resistance within the Florida parishes, and studies within two or three counties in Mississippi (Dinus 1969) and Georgia (Kinloch and Stonecypher 1969) have identified individual trees whose progenies have a high degree of resistance.

This paper describes in detail the pattern of geographic variation in rust resistance in that part of the loblolly pine range within Mississippi, the Florida parishes of Louisiana, and the parts of Alabama and Tennessee immediately adjacent to Mississippi. The main strength of the work lies in the intensity of the sampling. Progenies from 561 parent trees were tested.

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[1] The authors are Forest Geneticist at the Institute of Forest Genetics, Southern Forest Experiment Station, USDA Forest Service, Gulfport, Mississippi; and Professor of Forestry, Mississippi State University, State College, Mississippi, respectively. They thank Crown Zellerbach Corporation for providing a planting site in Livingston Parish, Louisiana, Warren Nance for developing the computer program used to analyze the data, and E. B. Snyder for helping plan the study.

The collection locations were planned by dividing the State into 20 latitudinal transects, 15 minutes of latitude apart, and mapping a collection point every 30 miles along the transects. Collections were made within 10 miles of these points. Cones were taken from five trees at each of 115 locations during 1962, 1963, or 1964. Six locations west of the Mississippi River were also sampled to provide a basis of comparison with previous work. Loblolly pine is ubiquitous within the study area, and criteria for selecting the parent trees were undemanding. The first five trees that were sighted from the road within the specified location were chosen provided that they had cones and were easy to climb. The latter provision meant a maximum of about 30 feet to the first limb. It also meant that most of the trees were young and less than 50 feet tall. Presence or absence of cankers was not considered. In addition, the selected trees were between 200 feet and one-fourth mile apart and were within 100 feet of other cone-bearing loblolly pines. Obvious hybrids with longleaf pine (*P. palustris* Mill.) or shortleaf pine were bypassed, and if trees of other species occurred in mixture, their presence was noted.

Planting stock was grown in a three-replicate design near Gulfport, Mississippi, during 1965. Fungicide was applied five times to exclude rust infection in the nursery, and no galls were observed on the stock. The seedlings were planted during the winter of 1965-66 in three locations: 15 miles east of Baton Rouge, Louisiana, central Mississippi, and northwestern Alabama. Stock at each location was from a single nursery replication. The design was a 10-replicate, compact family block with two-tree (family) plots (Panse and Sukhatme 1954). "Family" as used here means the wind-pollinated progeny of a single tree. This design grouped the five two-tree family plots representing a single stand (the five trees in each collection area) rather than distributing the family plots at random over each replication. Spacing was 8 by 8 feet and replication size was about 1.7 acres. A single border row was used to offset edge effects.

Rust infection in the Louisiana planting has been heavy. Forty-three percent of the trees have either a branch or a stem gall. This, coupled with good survival and growth, prompted us to score the planting for rust infection during the winter of 1969-70, when it was 4 years old. The average number of both trunk and branch cankers per tree was determined. Results from the remaining two plantations will be reported as they are developed.

Analyses.--The data were transformed to $\sqrt{X + 1/2}$, and $\sqrt{X}\ (\sqrt{X + 1})$. Raw and transformed data from several stands were plotted, and $\sqrt{X + 1/2}$ approached normality closest; therefore analysis of variance was done with this transformation.

First, 115 separate analyses of variance were conducted on the five families from each stand. Degrees of freedom for typical analysis were: blocks--9, families--4, error--36, total--49.

Then, an analysis combining data from all stands was made as follows:

Source of variation	D.f.	S.S.	M. Sq.	Variance components
Blocks	9	27.46	3.051	
Stands	104	149.82	1.440*	$\delta_e^2(a) + 10\ \delta_s^2$
Error (a): stands x blocks	936	135.82	.145	$\delta_e^2(a)$
Families within stands	401	130.54	.326*	$\delta_e^2(b) + 10\ \delta_f^2$
Error (b): families within stands x blocks	3,238	577.79	.178	$\delta_e^2(b)$

The 0.05 level of significance was used.

The "families within stands" and "error b" in the combined analyses terms were determined by pooling the "family" and "error a" terms from each stand analyses. Prior to pooling, tests of homogeneity were conducted and data from four stands were removed because of excessive heterogeneity. The six stands west of Mississippi were also removed, because of their geographic isolation from the population east of the Mississippi River.

RESULTS

The geographic pattern of variation is shown in figure 1 in terms of cankers per tree averaged over the five families from each collection area. The values range from near 2.4 for the progenies from the collection areas immediately west of Mobile Bay to 0 for one of the progenies from east-central Arkansas.

The most obvious geographic effect is the relative resistance of the progenies from west of the Mississippi River compared to those from east of it. This confirms earlier evidence that resistance in loblolly pine is widespread west of the Mississippi River.

The most important new aspects of the variation pattern are (1) the distribution of stands with a high degree of resistance in the Florida parishes of Louisiana and southwestern Mississippi, and (2) the lack of resistance in the progenies from the southeastern part of the study area and the general increase in resistance to the north and west. Inherent resistance is higher along the western margin of the range in Mississippi than it is along the Alabama-Mississippi border.

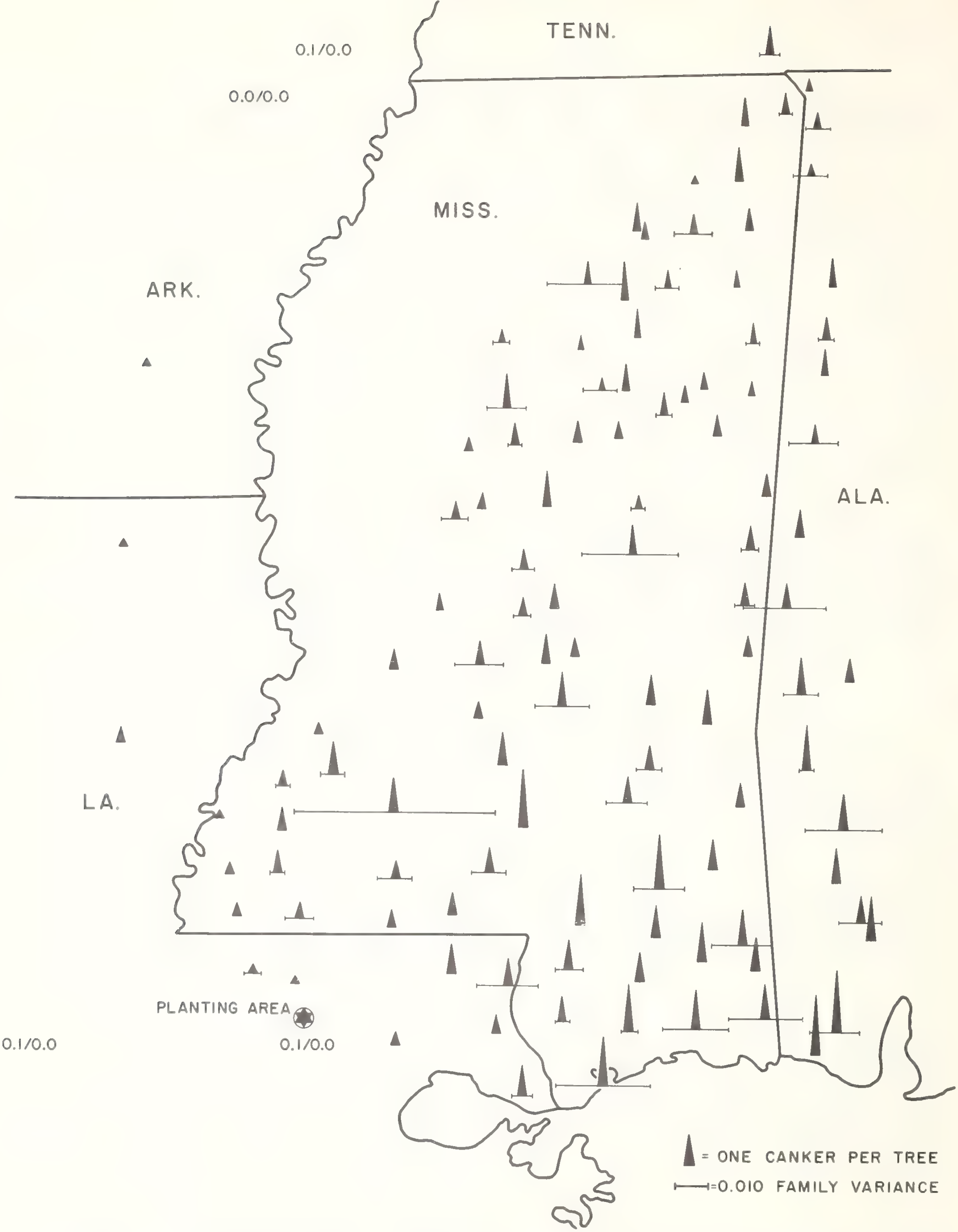

Figure 1.--Average number of cankers per tree (vertical triangles) for the progenies of 115 stands of loblolly pine. The horizontal bars represent variation among the (usually) five families from each stand. The fractions state canker/variance values too small to depict grapically.

It is easier to report these variations than to explain them. One possibility is hybridization between loblolly and the resistant shortleaf pine.

Introgression with shortleaf is almost certainly important in the development of resistance in loblolly pine (Hare and Switzer 1969). However, correspondence between the distribution of shortleaf pine (fig. 2) and the geographic variation in resistance of loblolly is only fair. Shortleaf is absent or rare within about 30 miles of the Mississippi Gulf Coast where resistance is low, and it is common in southwestern Mississippi where resistance is high. Concentrations of shortleaf are particularly heavy and resistance particularly high west of the Mississippi River. On the other hand, resistance in loblolly is fairly high in parts of northeastern Mississippi where shortleaf is relatively scarce.

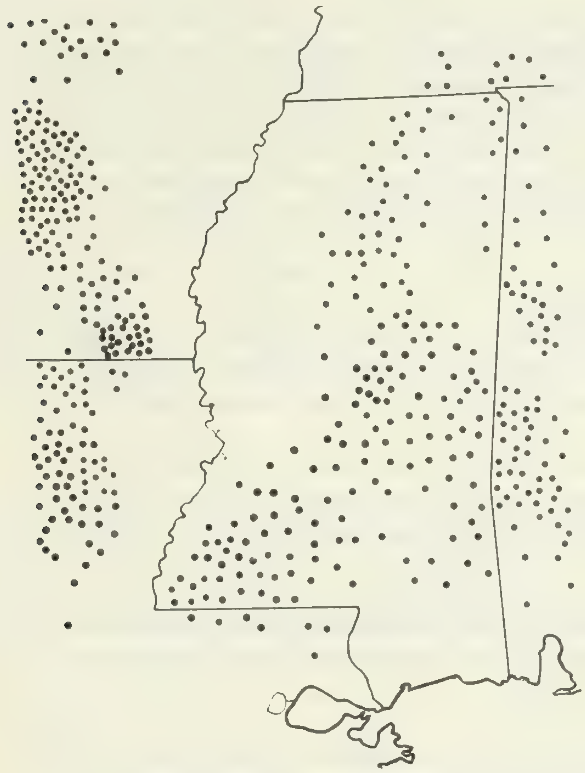

Figure 2.--Distribution of shortleaf pine in and near the study area. Each dot signifies 5,000,000 cubic feet of timber volume in trees at least 5.0 inches in diameter at breast height. (Adapted from Janssen and Weiland 1960.)

The presence of shortleaf was noted for each collection area where it occurred; the notes agreed very well with the shortleaf distribution map shown in figure 2 but revealed nothing further about the relationship between resistance in loblolly and the distribution of shortleaf.

Introgression may also be at least partly responsible for the very large differences in amount of family variance within stands (fig. 1). Large family variance would be expected in early stages of introgression before resistant genes become evenly distributed throughout the population.

Still other factors may contribute to the pattern of resistance. Climatic characteristics of the environment or introgression with longleaf may be involved, either singly or in combination. Resolution of the problem would undoubtedly be greatly aided by a fuller knowledge of the genecology of the rust.

Variance within stands was 0.0148, and variance among stands (the geographic effect) was 0.1294, or 8.75 times as great. This result provides a guide for efficient selection for rust resistance in loblolly within the study area and probably outside it as well, since the area covered is representative of most of the loblolly range. First priority should be given to selection of resistant stands. Once this has been done, individual trees may be selected within the best stands.

The large variation attributable to stands simplifies the problem of making use of resistance once it is located. Seed can be collected from resistant natural stands in large quantities, whereas resistant individual trees must be propagated and multiplied in orchards. Collecting seed from a stand should also ensure a broader genetic base than could be had by picking a few individual trees, and would thus reduce the chances of heavy loss if the pathogen evolved new races capable of infecting the presently resistant selections.

LITERATURE CITED

Crow, A. B. 1964. Ten-year results from a local geographic seed source study of loblolly pine in southeastern Louisiana. La. State Univ. For. Note 57, 4 pp.

Dinus, R. J. 1969. Testing slash pine for rust resistance in artificial and natural conditions. Tenth South. Forest Tree Improv. Conf. Proc. 1969: 98-106.

Hare, R. C., and Switzer, G. L. 1969. Introgression with shortleaf pine may explain rust resistance in western loblolly pine. USDA Forest Serv. Res. Note SO-88, 2 pp.

Henry, B. W. 1959. Diseases and insects in the Southwide Pine Seed Source Study plantations during the first five years. Fifth South. Forest Tree Improv. Conf. Proc. 1959: 12-15.

Janssen, P. L., and Weiland, M. R. 1960. Softwood distribution maps for the South. USDA Forest Serv., South. Forest Exp. Stn., New Orleans, La., and Southeast. Forest Exp. Stn., Asheville, N. C., 12 pp.

Kinloch, B. B., and Stonecypher, R. W. 1969. Genetic variation in susceptibility to fusiform rust in seedlings from a wild population of loblolly pine. Phytopathology 59: 1246-1255.

Panse, V. G., and Sukhatme, P. V. 1954. Statistical methods for agricultural workers. Indian Counc. Agric. Res., New Delhi, 361 pp.

Wells, O. O., and Wakeley, P. C. 1966. Geographic variation in survival, growth, and fusiform-rust infection of planted loblolly pine. Forest Sci. Monogr. 11, 40 pp.

EARLY IDENTIFICATION OF FUSIFORM RUST RESISTANT SLASH PINE FAMILIES THROUGH CONTROLLED INOCULATION

R. E. Goddard and R. A. Schmidt [1]

The impact of fusiform rust on many slash pine plantations needs no further elaboration. A viable alternative to susceptible planting stock is urgently needed. As a temporary expediency, planting a resistant species such as shortleaf pine in certain areas where high infection rates can be anticipated could be advantageous. In the long run, however, for sites on which slash pine is the most productive species, resistant varieties of slash pine should be developed.

As discussed in the previous paper by Schmidt and Goddard (1971), some fairly resistant lines of slash pine are being identified in regular progeny tests. However, there are frequent inconsistencies in comparing results from different tests. Although some field tests provide useful information, in many other tests the disease incidence is so low that little or no reliance can be placed on family rust ratings. Also, at best three, or preferably, five years are required for disease evaluation.

To provide rust data for all select families used in the University of Florida Cooperative Forest Genetics Program, and to obtain this information at a more rapid pace than possible through the standard progeny testing program, a special rust screening project is underway. Because they presumably already have other desirable traits, progenies of seed orchard clones receive first consideration. Other potential sources of rust resistance are also being tested.

PROCEDURES

The current screening program was started in 1969 on a modest scale to test procedures and has been continued annually with slight modifications. Seed resulting from open pollination in orchards (half-sibs) were pregerminated in petri dishes and planted in small peat pots. The pots were arranged in flats, each flat containing 48 seedlings. Randomly placed in each flat were single seedlings from 46 families plus seedlings of one line which had repeatedly shown very high susceptibility in field tests, included as a susceptible check. Fifty such flats of seedlings were moved in mid-May, approximately two months after germination, to shelves in a screening shed constructed for maintenance of high humidity.

Telia-bearing oak leaves were distributed on wire frames directly over the seedlings. To assure an ample supply of infected oak leaves, locally collected aeciospores were used to inoculate expanding laurel and water oak leaves during the spring a few weeks prior to pine inoculation. Moist muslin was draped over the wire frames and shelves, and canvas over the entire shed was kept wet, maintaining a relative humidity within the shed of 100%. Glass slides were placed in each flat to monitor the number and distribution of Cronartium fusiforme sporidia. Seedlings were kept in the shed for 72 hours and then placed in nursery beds.

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[1] Associate Professor of Forest Genetics and Assistant Professor of Forest Pathology, respectively, School of Forestry, University of Florida, Gainesville.

The same seedlings were again inoculated at approximately one year of age in the nursery beds by similar procedures. Metal frames were placed over the nursery beds to support the frames of oak leaves and the entire outer frame was covered with canvas. The covering tent was kept wet to maintain high humidity around the seedlings. Slides for spore counts were again distributed through the bed.

Gall counts were made the winter after shed inoculation and again in December after the nursery bed inoculations. Separate tally by gall location identified infection from shed or nursery inoculation. Data are presented as percent of trees galled in each family.

For 1970 shed inoculations, seedlings were grown on Jiffy 7 peat pellets. The flats hold 7 rows of 10 pellets. Half-sib families were placed in 10-tree rows. There are six shelves in the shed and each shelf constituted a block. Row-plots were randomized on each shelf.

Included were half-sib families of 163 select slash pines and 138 half-sib families from a special rust free seed production area. As 10-tree plots of over 300 families repeated six times exceeded the capacity of the inoculation shed, three groups of progenies were inoculated in sequential inoculations during the first two weeks of April. In Group I were 112 select tree families plus 25 half-sib families from the special seed production area. Group II consisted of 113 families from the seed production area. In Group III were 51 families of Buckeye Cellulose Corporation selections grown by them and brought to the shed for inoculation. The susceptible check was included in each group.

The special rust free seed production area referred to above was established by Brunswick Pulp and Paper Company in a young slash pine plantation severely infected with fusiform rust (over 90% of trees with galls). All infected trees were removed. Residual trees are now producing cones and open-pollinated progenies of individual trees in this stand were inoculated as described above.

A third phase of the rust screening project is establishment of seedlings from the same families (not the identical seedlings used in shed and nursery phases) in four high risk locations--one each in east Georgia, west Georgia, north Florida and south Alabama. Initial plantings of these tests were made in 1971. No data are yet available and evaluation will not be completed until at least three years after establishment.

Testing for rust resistance of progenies of the several hundred clones used in the Florida program will not be completed before 1975, and ultimate success of the project must be based on reliable identification of resistant lines. However, useful preliminary data from the controlled inoculation phases are already being generated.

RESULTS

Comparison of Shed and Nursery Inoculations

Results of both shed and nursery bed inoculations are available for the 46 select families initially inoculated in 1969. Mean infection resulting from shed inoculation was 48.1% with individual family means ranging from 22.5 to 69.2%. Infection resulting from inoculation at age 1 year averaged 59.3%, ranging from 15.4 to 88.5%. In both cases, there were significant differences among individual families. Family rust percents from the two inoculations had a correlation coefficient (r) of 0.52 (Figure 1). This

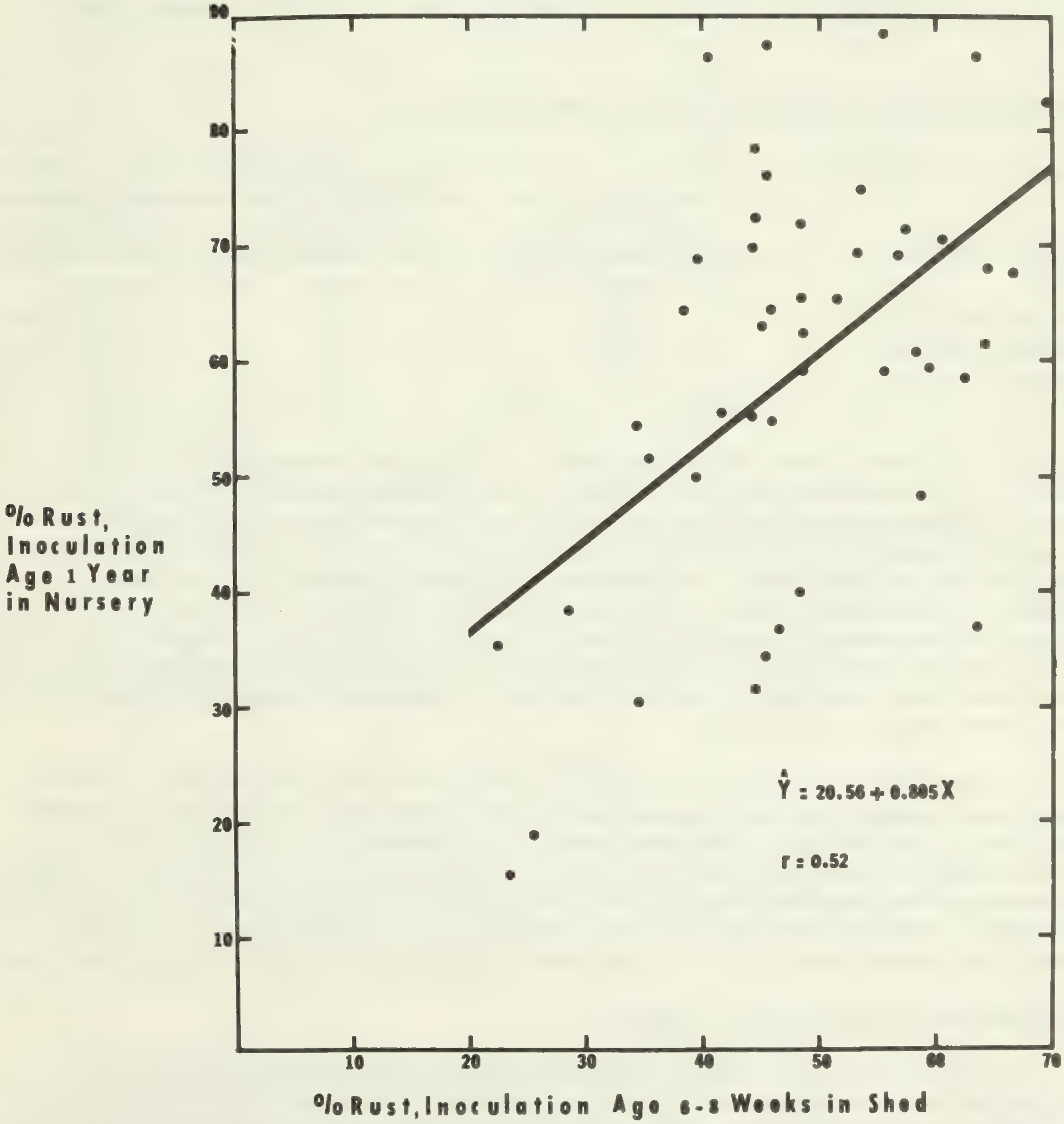

Figure 1.--Percent rust infection of individual slash pine select tree families inoculated at 6-8 weeks following germination plotted against percent rust infection of the same individuals inoculated at age 1 year.

value with 45 degrees of freedom is highly significant but does not indicate that resistance to infection during the primary needle stage is highly predictive of resistance at the later developmental stage. However, at least two of the families had consistently low infection following both inoculations. Additionally, five of the ten families with lowest infection rates as young seedlings were among the ten lowest when inoculated at one year of age in the nursery bed. Similarly, most of the families with high susceptibility in the shed had high rust percent from nursery inoculations.

1970 Shed Inoculations

General results of inoculations in the shed in 1970 are summarized in Table 1.

Table 1.--General results of 1970 shed inoculations

	Percent Rust		
Mean Values	Group I 137 families	Group II 113 families	Group III 51 families
Test	40.7	53.4	77.5
Lowest Family	7.7	22.2	44.8
Highest Family	80.7	85.7	91.7
Susceptible Check	51.7	73.1	69.2

Within each group there are significant differences among infection percents. It is obvious that uniformity in infection percent was not achieved among the three separate inoculations. Yet, in each case, sufficient inoculum with satisfactory distribution was applied to differentiate among the families in any one test. The susceptible check, chosen on the basis of high infection rates under field conditions, was somewhat disappointing as it was seldom among the very highest in rate of infection. However, in each block of each inoculation group, a substantial portion of susceptible check seedlings had galls, giving further indication of adequate quantity and distribution of sporidia.

In the first inoculation group, 25 families from the Brunswick Pulp and Paper Company seed production area were included along with 112 select families. The average infection rate of the progenies of special rust free selections was 41.6% in contrast to 39.8% for the plus tree families. It appears that neither the general resistance level nor frequency of highly resistant families was greater for rust selections than for the general plus tree selections, at least in the early primary needle stage.

Relationship to Field Test Results

Data on rust from natural inoculation in regular progeny tests were available for approximately 70 of the families included in 1970 shed inoculations. Although only a few of these families were in any one test or series of tests, comparisons of rust infection percentages under the two conditions do indicate trends. Correlation coefficients were calculated using family rust infection percents for lines inoculated in contrast to results in a single field test or the mean rust percents in a series of field tests (Table 2). The r values were rather variable, but the values for series of tests were quite high in most cases. If the mean infection in several tests is the best estimate of relative resistance under field conditions, it appears that controlled inoculation gave a fairly good indication of relative resistance. For families not adequately field tested, shed inoculation results can be accepted with some confidence.

Table 2.--Correlation coefficients comparing rust infection percents of families common to field progeny tests and 1970 shed inoculations

Field Progeny Tests	No. of families in common	Mean Infection % Shed[1]	Mean Infection % Field Tests[1]	r
Test 6-4	7	42.5	10.1	.67
Test 6-6	7	42.5	8.7	.78
Test 6-7	7	42.5	9.9	-.27
Means, Tests 6-4, 6-6, 6-7	7	42.5	9.6	.83*
Means, Tests 6-10, 6-15	5	34.4	20.0	.71
Means, Tests 1-6, 1-7	6	39.6	21.7	.32
Means, Tests 1-8, 1-9	12	35.3	15.6	.61*
Means, Tests 1-8, 1-9 1-12, 1-13	6	31.1	20.7	.56
Means, Test 4-3, 4-4, 4-5	5	44.5	62.1	.44
Means, Test 7-6, 7-7, 7-8, 7-9	6	38.2	31.2	.66

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* Significant at .05 level

[1] Means are for the common families, not for the entire test.

DISCUSSION

On the basis of two years results from shed inoculations and one year results from nursery inoculations, it is evident that there is substantial genetic variation in slash pine in respect to susceptibility to fusiform rust and that relative susceptibility can be differentiated by the procedures used. There is no evidence of complete resistance among the slash pine families tested, but some lines are consistently low in percentage of trees infected.

The significant correlation coefficient for infection percents from shed and nursery inoculations indicates fair consistency of performance at the two stages of development. The repeatability was not as high as would be desired. However, utilizing data from 1969 shed inoculations and from inoculations of the same seedlings in nursery beds one year later, resistant families were identified.

Inoculation during the primary needle stage also gives a fairly good indication of families more likely to have reduced infection rates under field conditions. Correlation coefficients for rust following shed inoculation versus natural inoculation, although with limited numbers of families, indicated a rather strong positive agreement, especially when mean values for several field tests were used. Results obtained are in general agreement with those reported by Dinus (1968) for six slash pine families compared for inoculation under artificial and natural conditions.

Rather intensive selection against fusiform rust susceptible trees in an area of high infection was disappointing. The proportion of trees with high levels of resistance among progenies was no greater than with general plus tree selections. These results are in direct contrast to a similar study reported by Dinus (in press) in this conference. The conflicting findings may in part be related to test locations. In Dinus' study, phenotypic rust resistant selections were made in Mississippi and progenies inoculated with rust from Mississippi. In our case, selections were made in a stand near Jessup, Georgia, and the progenies were exposed to rust from Gainesville, Florida. Thus, there is possibility of variation in the rust fungus. Also, data to date are related only to susceptibility of progenies during the primary growth stage and perhaps increased resistance during later developmental stages will become apparent.

There are some suggestions of changes in relative resistance with increased age. Some lots appear to be much more susceptible at the primary needle stage than at later stages of development. The reverse may also be true with some lots seemingly increasing in susceptibility with age. There is enough shifting of relative resistance level at later stages to question selection for resistance solely on the basis of early inoculation. Variation in relative rust infection between tests, either under natural or controlled conditions, is enough to doubt the reliability of any single test. However, in conjunction with data from natural inoculations at later stages of development, early inoculations provide substantial help in identification of resistant seed sources.

LITERATURE CITED

Dinus, R. J. 1969. Testing slash pine for rust resistance in artificial and natural conditions. Proc. Tenth South. Conf. Forest Tree Imp. p. 98-106.

Dinus, R. J. (in press). Phenotypic selection for fusiform rust resistance. Proc. Eleventh South. Conf. Forest Tree Imp.

Schmidt, R. A. and R. E. Goddard. (in press). Preliminary results of fusiform rust resistance from field progeny tests of selected slash pines. Proc. Eleventh South. Conf. Forest Tree Imp.

PRELIMINARY RESULTS OF FUSIFORM RUST RESISTANCE FROM FIELD PROGENY TESTS OF SELECTED SLASH PINES

R. A. Schmidt and R. E. Goddard [1]

Southern fusiform rust incited by the fungus Cronartium fusiforme Hedgc. & Hunt ex Cumm. is of prime importance to the management of slash pine (Pinus elliottii Engelm. var. elliottii) in many areas of the Southeast. This is especially so since intensive cultural practices which enhance growth appear to predispose pines to infection by C. fusiforme. Results of a recent unpublished survey of 1290 slash pine plantations (age 5-22 years) in 39 counties in Florida and Georgia indicate that in the average county 31.8% of the trees have fusiform rust. Counties with average values over 50% are not uncommon. Although these results include branch and stem galls, the extent of stem damage and mortality appears proportional to the total incidence of the disease. Within high-hazard rust areas the advisability of continued use of susceptible slash pine for commercial wood production is questionable.

Believing that genetic disease resistance offers a feasible control method, slash pine selections in the Cooperative Forest Genetics Research Program at the University of Florida are being screened for resistance to C. fusiforme. Hopefully, the extent and nature of such resistance will be determined so that plans can be made for its utilization in the tree improvement program. Rust data resulting from natural inoculation of pines of known parentage are presented in this paper. Select families and other seed sources were examined for differential response to C. fusiforme and for consistent performance among tests.

METHODS

Selection of slash pine.--Within the Florida program, approximately 1200 slash pines were selected from the species range, primarily on the basis of growth parameters and form quality. Trees with fusiform rust were avoided, but upon re-examination galls were found in crowns of a few selections. In total, few ortets used in seed orchards had any indication of rust. Selection against rust in certified seed production areas was equally or more stringent. For certification by the Georgia Crop Improvement Association, there must be no rust galls in the seed production area or the isolation zone. However, neither select trees nor seed production areas were necessarily in high-rust hazard areas. Also, the trees in both cases were normally over 25 years old at time of selection and galls that may have been present on lower limbs were shed before selections were made.

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[1] Assistant Professor of Forest Pathology and Associate Professor of Forest Genetics, respectively, School of Forestry, University of Florida, Gainesville.

Progeny test designs.--Progeny resulting from open-pollination within seed orchards or control-pollination were established in field tests to evaluate their select tree parents. Open-pollinated tests were a randomized block design having 5 to 10 blocks of 7 to 10-tree row plots. Check lots consisted of 1 to 4 different bulk seed lots repeated twice in each block. Progeny tests of control-pollinated crosses were similar except that there were only 4 blocks. Approximate locations of these progeny tests are shown in figure 1.

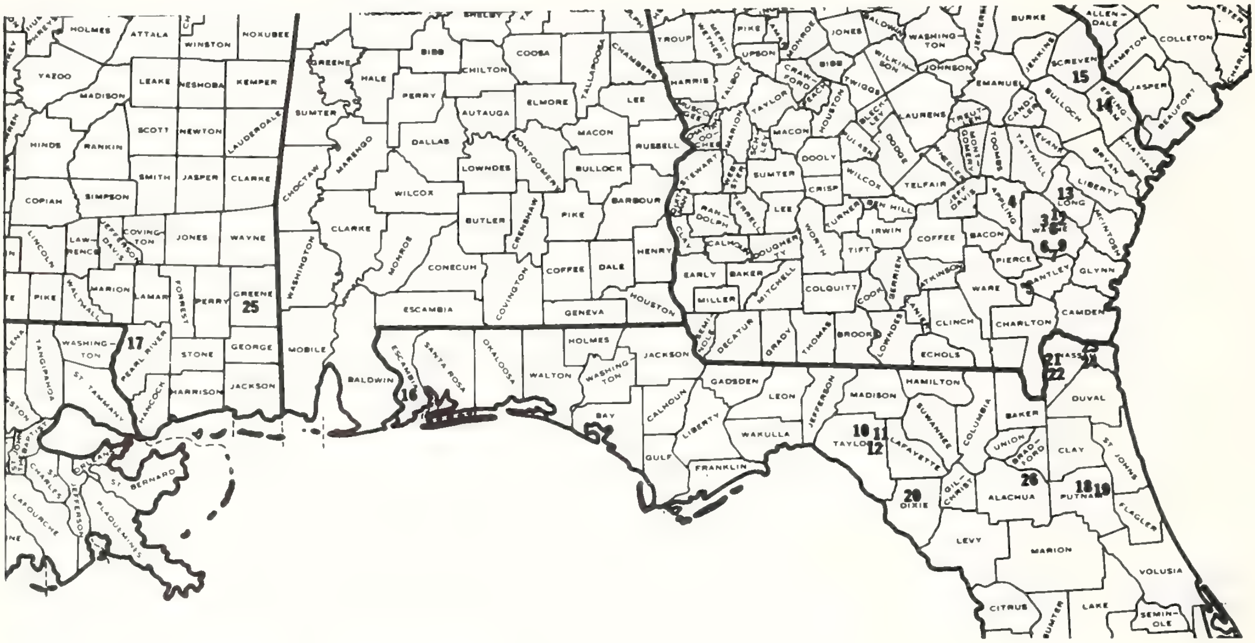

Figure 1.--Locations of select tree progeny tests in Fla., Ga., and Miss.

With regard to seed production areas, Continental Can Company established tests in five locations using progeny from several certified seed sources. Four randomized blocks of 25-tree plots were planted in each location. Also included in these tests were progeny from trees in the rust-free isolation zone around the seed production area and bulk seed lots from adjacent stands.

Analyses of rust data.--In each instance data are given as percent rust, i.e., the percent of trees with a rust gall, branch or stem, and represent a 100% sample. Differential response among families within individual tests was determined by an analysis of variance, using variance among plots of check lots as a measure of experimental error.

Linear correlation analysis was used to evaluate consistency of performance of families included in two or more progeny tests.

Comparisons between means of select families and check lots were made with Student's paired "t" test.

RESULTS

Select slash pine progeny tests.--The incidence of fusiform rust in 26 progeny tests is presented in table 1. Averages of select families range from 3.0 to 59.8% and those of check lots from 1.3 to 55.8%.

Table 1.--Results of analyses of the incidence of fusiform rust in progeny tests of select slash pine

Progeny Test No.[a]	No. of Select Families	Ave. % Trees With Rust: Select Families	Ave. % Trees With Rust: Check Lots	Results of ANOV[d]: Block Means	Results of ANOV[d]: Family Means
1	7	43.6[c]	34.6[c]	NS	NS
2	5	30.8[c]	25.2[c]	NS	**
3	12	43.4	32.0		
4	35	34.3[c]	28.5[c]	NS	*
5	34	23.1[c]	13.6[c]	NS	**
6	56	4.6	1.3		
7	56	4.6	6.0		
8	42	28.9	15.6		
9	42	25.7	17.5		
10	23	6.3	4.6	**	NS
11	22	13.1	11.7	*	**
12	19	3.7	2.3	NS	NS
13	28[b]	58.2	41.2	NS	**
14	19[b]	56.8	38.2	*	**
15	12[b]	58.9	35.0	**	**
16	34	9.5	8.8	NS	*
17	27	59.8	55.8	NS	**
18	21	3.0	3.0		
19	20	6.0	3.4		
20	14	4.0	1.3		
21	9	42.2	33.1		
22	10	31.3	19.5		
23	49[b]	8.2	8.2		
24	47[b]	9.7	5.9		
25	15	12.7	14.5		
26	15	11.3	9.9		
	Ave.	24.37	18.10		

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[a] Numbers correspond with figure 1.
[b] Control-pollinated families; all others are open-pollinated.
[c] Fifth-year data; all others are third-year data.
[d] Analysis of variance; **,*, and NS = significant at .01, .05, and non-significant, respectively.

The average for all tests is 24.37% for select families and 18.10% for check lots. Check lots had significantly fewer diseased trees (5% level) than select families.

A summary of the analysis of variance of percent rust of 12 progeny tests is also given in table 1. In most instances block means were not significantly different and, more important, select family means were significantly different. Sample data for test #4 (Brunswick Pulp and Paper Company test #6) were as follows. The average percent rust for the 35 select families was 34.3%, ranging from 8.6 to 71.4%. Check lots were 28.0, 32.4 and 25.0% diseased. Differences among select family means were significant at the 5% level.

Consistency in family performance, as judged by the correlation coefficient (r) between percent rust of families located in two or more progeny tests, was examined. A portion of these data, i.e., those tests having at least 14 families in common (12 degrees of freedom), are given in figure 2. As expected, test pairs with less than 12 degrees of freedom gave erratic "r" values and were deleted from the figure. A preliminary analysis (Goddard and Strickland 1970) suggested that "r" values were positively related to the mean percent rust for the two progeny tests being compared. Thus, the statistical significance or nonsignificance of the "r" values are shown in relation to the progeny test means.

In general, significant "r" values occurred when both progeny test means were relatively high, e.g., 20% or greater. Comparisons of family performance when one or both progeny test means were low usually yielded non-significant "r" values. Two notable and, perhaps, predictable exceptions occurred. One comparison of control-pollinated families yielded a significant "r" value regardless of the fact that both progeny test means were quite low. Comparisons of control-pollinated families in several progeny tests with high percentages of rust yielded very high "r" values. Second, comparisons of third- and fifth-year data from a single test yielded a significant "r" value in spite of low test means.

A noteworthy result not evident from figure 2 was that progeny test #7 (table 1) was unlike other tests with which it had families in common. Of eighteen such comparisons, including both third- and fifth-year rust data, all "r" values were near zero; several were negative.

Percent rust in one control-pollinated progeny test of four males and thirteen females is given in table 2. This test, one of several established by ITT-Rayonier, was measured 5 years after planting. In spite of low rust incidence specific combinations have substantially more rust than others. One male and several females have progeny with above average percent rust, regardless of the other parent. When these "high-rust" parents were crossed with one another relatively high rust percentages resulted. The amount of rust on these crosses was significantly correlated with that present on the same crosses established on different sites in the same year.

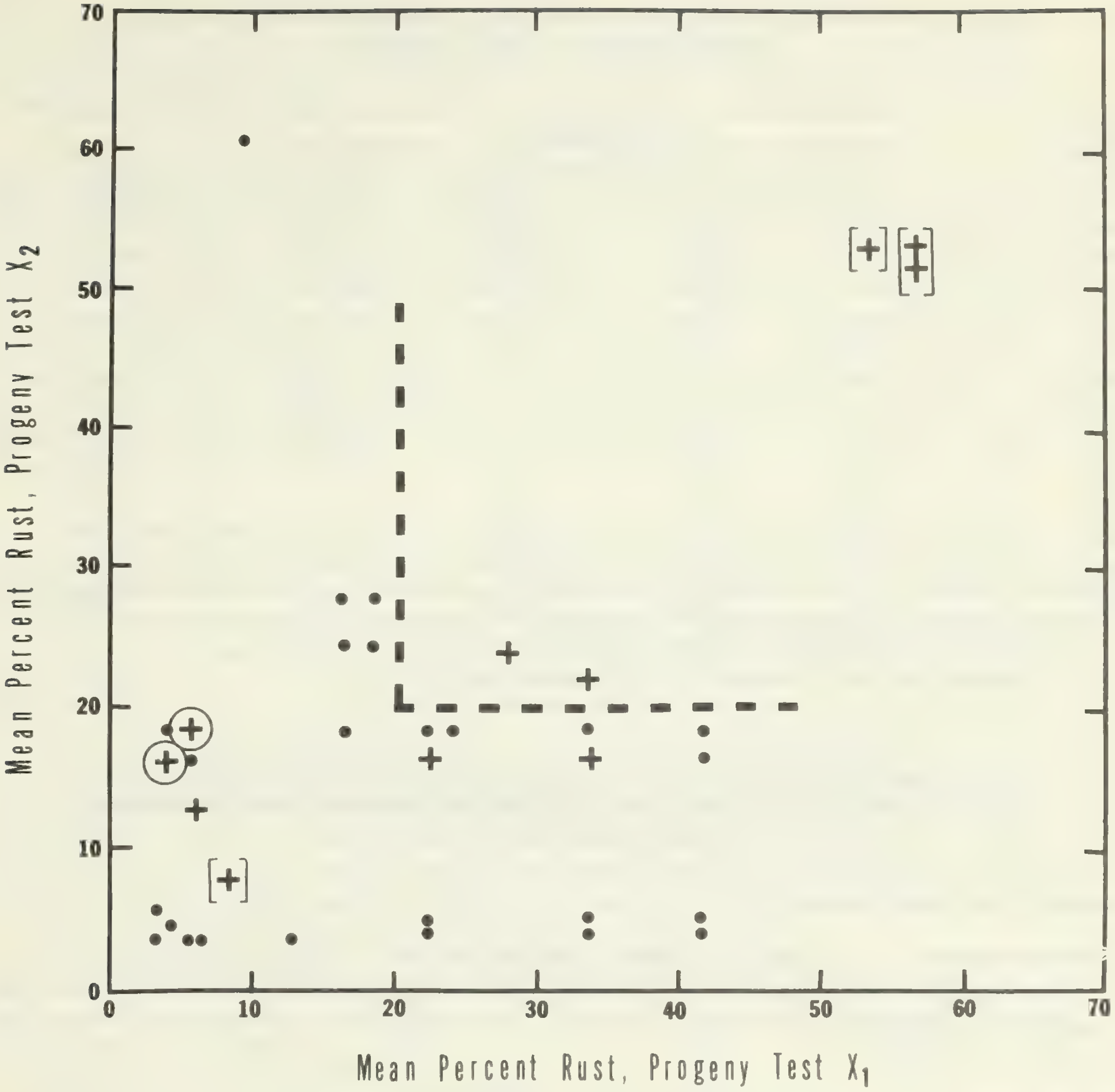

Figure 2.--Results of linear correlation analyses of mean percent rust for families located in two progeny tests shown in relation to the mean percent rust in the two progeny tests, X_1 and X_2. + = statistically significant at the 5% level, ● = non-significant, O = 3rd vs 5th year rust data for a progeny test, and [ ] = control-pollinated progeny test.

Seed production area progeny tests.--Of the five tests of seed production area progeny established by Continental Can Company, three having substantial amounts of rust are summarized in table 3. These data, taken at age five, give percent rust for progeny of the seed production area, the surrounding rust-free isolation zone, and bulk seed from an adjacent stand. There was no significant difference among combined means for the three test sites and no improvement in rust resistance of the progeny from the seed production area.

Table 2.--Percent of trees with fusiform rust in a control-pollinated progeny test after 5 years

Female Parent[a]	Male Parent[b]				
	101	118	110	502	Mean[c]
101			10.3	2.7	6.5
104		5.1	8.3	2.6	5.3
105	0.0	10.8	21.6	28.2	15.2
107	16.7	12.8	10.5	23.7	15.9
109	5.9	2.6	5.4	10.8	6.2
501	7.9	2.6	2.7	16.1	7.3
602	5.3	7.7		20.5	11.2
1104	10.3	5.4	13.5	13.5	10.7
1201		5.3	2.6	11.1	6.3
1204	0.0	2.6	2.8	12.5	4.5
6104	7.5	10.5	5.1		7.7
6107	8.1	2.8	5.4	10.3	6.6
6117		10.3	10.8	2.5	7.9
Mean	6.9	6.5	8.2	12.9	8.6

[a] F value for female parents significant at 1% level.
[b] F value for male parents significant at 1% level.
[c] The means for the two check lots were 3.8 and 10.3%.

Table 3.--Average percent trees with rust in open-pollination progeny from a seed production area, isolation zone and adjacent stand planted in three locations

Seed Source	Test Site			Mean
	Emanuel County Georgia	Bryan County Georgia	Jasper County South Carolina	
Long County Certified Seed Production Area	48	50	59	52.0
Isolation Zone	34	53	50	46.8
Adjacent Stand	31	50	55	46.0

DISCUSSION AND CONCLUSIONS

Data from natural inoculations of open- and control-pollinated families show that the average percent rust was greater on progenies of select slash pine than on bulk seed check lots. This is not surprising in that (i) selections were not necessarily made from high-hazard rust areas, (ii) branch galls could have been naturally pruned from selected trees prior to selection, and (iii) selection for vigor could be positively related to susceptibility to an obligate parasite such as *C. fusiforme*. Nevertheless, there were significant differences among select families as some had substantially less rust than other families and check lots. Results similar to these have been reported (Barber 1961; LaFarge and Kraus 1967; Webb and Barber 1966) although the latter paper found select tree progeny to have less rust than check lots.

Comparisons of percent rust between families established in two or more progeny tests indicate that (i) open-pollinated families were consistent between tests when both progeny tests had relatively high mean rust percentages, (ii) control-pollinated families were more consistent than open-pollinated families even when the former were established in progeny tests with low mean percent rust and (iii) third- and fifth-year rust percentages were positively correlated. Thus, it appears that reliable identification of rust resistant families can be made from control-pollinated tests at low levels of disease while identification of resistant families in open-pollinated tests is more feasible at relatively high levels of rust.

The one example of a strong genotype x site interaction is difficult to explain solely on the basis of racial variation in the fungus as the locations are near to one another. Perhaps, it is, in part, due to the low level of disease incidence. In general, these data agree with those of others (Kinloch and Stonecypher 1969) who reported little genotype x site interaction.

An analysis of the amount of rust on full-sib progeny in a control-pollinated test indicated that progeny of certain male or female parent trees have more rust, regardless of the other parent, than do other progeny. Crosses between these high-rust parents yielded progeny that had more rust than progeny having only one high-rust parent. Similar conclusions were reached (Kinloch and Stonecypher 1969) for loblolly pine.

Further evidence of the failure of phenotypic selection to increase rust resistance of progeny is indicated by the lack of difference in the amount of rust among the progeny of the seed production area, the isolation strip and adjacent stand.

In conclusion these data suggest the following with regard to rust resistance.

1. The average rust resistance of half-sib families of the select slash pine in the Florida program is less than that of bulk seed check lots.

2. Half-sib families of some selections are substantially more rust resistant than others and more so than bulk seed check lots.

3. Consistent disease ratings for half-sib families were evident at relatively high levels of rust.

4. Consistent disease ratings for full-sib families were evident at low levels of rust and, in general, their ratings were more consistent than those of half-sib families.

5. Disease ratings of half-sib families were similar for third- and fifth-year measurements.

6. One instance of a site-genotype interaction was evident although generally few such interaction occurred.

7. Full-sib families from male and female parents which consistently yielded rust susceptible progeny were more susceptible than families having only one high-rust parent.

8. Progeny from a rust-free seed production area gave no evidence of increased rust resistance when compared with check lots from adjacent stands.

LITERATURE CITED

Barber, J. C. 1961. Growth, crown form, and fusiform rust resistance in open-pollinated slash pine progenies. Proc. Sixth South. Conf. For. Tree Improv., p. 97-104.

Goddard, R. E. and R. K. Strickland. 1970. Cooperative forest genetics research program. 12th Prog. Rept., Univ. Fla., School of For., Res. Rept. No. 18, 36 p.

Kinloch, B. B., Jr. and R. W. Stonecypher. 1969. Genetic variation in susceptibility to fusiform rust in seedlings from a wild population of loblolly pine. Phytopathology 59: 1246-1255.

LaFarge, Timothy and J. F. Kraus. 1967. Fifth-year results of a slash pine polycross test in Georgia. Proc. Ninth South. Conf. For. Tree Improv., p. 86-91.

Webb, C. D. and J. C. Barber. 1966. Selection in slash pine brings marked improvement in diameter and height growth plus rust resistance. Proc. Eighth South. Conf. For. Tree Improv., p. 67-72.

BROWN-SPOT RESISTANCE AMONG PROGENIES OF LONGLEAF PLUS TREES

Harold J. Derr[1]

Abstract.--Forty wind-pollinated seedlings from each of 227 longleaf pine (*Pinus palustris* Mill.) plus trees on national forests in Texas, Louisiana, Mississippi, Alabama, Florida, South Carolina, and North Carolina were planted at Alexandria, Louisiana, to test susceptibility to brown-spot infection (*Scirrhia acicola* (Dearn.) Siggers). After 2 years, family means ranged from 4 to 59 percent of diseased needle tissue. There was strong evidence of resistance among the selected parents, and evidence also of geographic influences. Nearby sources tended to be more susceptible than distant ones.

The study of resistance to the brown-spot needle blight has a long history at the Southern Forest Experiment Station and in the Mid-Gulf region, where the disease has commanded more attention over the years than elsewhere in the range of longleaf pine. By defoliating seedlings the blight retards growth, thus extending the grass stage of the trees and often causing heavy mortality.

Wakeley (1970) probably gave the first serious recognition to variation in host susceptibility when in 1928 he classified all seedlings in a planted stand according to their degree of infection. Some of his better trees are still identifiable and are being used for breeding. A few years later,Dr. A. F. Verrall observed resistant individuals in natural stands and made needle resin extractions to determine if resistance had a physiological base (Verrall 1934). Then in 1937 Dr. Paul V. Siggers, who later published results of a thorough study of the disease (Siggers 1944), found a highly resistant individual growing in a heavily infected, abandoned nursery in Louisiana, and he transplanted it to an experimental forest where it could be protected and preserved. Wind- and control-pollinated progeny of this tree have demonstrated that resistance is heritable (Derr and Melder 1970).

The search for resistant strains has been slowed by the necessity of screening progenies under field conditions, since the causal fungus, *Scirrhia acicola*, has not yet proved amenable to culture and inoculation.

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[1] The author is Principal Silviculturist at the Alexandria Forestry Center, Southern Forest Experiment Station, USDA Forest Service, Pineville, Louisiana.

Despite this difficulty, progenies of more than 900 trees have been field-tested, and some promising ones retested. Here I will report initial results of the latest test, which included the progenies of 227 trees growing throughout the longleaf pine range from Texas to North Carolina.

MATERIALS AND METHODS

The parents are superior-tree selections on southern national forests. It is generally assumed that screening for brown-spot resistance will be most profitable if confined to large dominants in even-aged stands. The premise is that superior growth is related to exceptional seedling vigor bestowed by resistance. Superior trees generally meet the requirement of dominance and are chosen for a number of other desirable traits.

Longleaf selections on the national forests total upwards of 450 trees, but only 227 bore seed in 1967, when the study was initiated. The 227 are distributed geographically as follows:

	No. of trees
Texas	42
Louisiana	33
Mississippi	22
Alabama--north	33
Alabama--south	22
Florida	25
South Carolina	37
North Carolina	13

Seeds were collected by ranger district personnel. In late March of 1968, approximately 44 seeds from each tree were sown in each of four nursery replications, which were arranged in a complete randomized block design. Seedlings received normal nursery culture, including one midsummer spraying with Bordeaux mixture for prevention of brown-spot. Seedlings were lifted in mid-November, potted, and stored outdoors until they were planted in early March.

The field test is on an unburned open site with a sandy, well-drained soil. It is approximately 20 miles southwest of Alexandria, Louisiana--on the Longleaf Tract of the Palustris Experimental Forest. An earlier longleaf planting adjacent to the test site indicated a moderate to severe brown-spot hazard. Seedlings were planted in shallow furrows to insure full exposure to spores; the furrows, in effect, accelerated the rate of disease build-up. A test plot contains 10 seedlings, and is replicated four times in a complete randomized block design. Post-planting culture was limited to control of pocket gophers and removal of silt from seedlings that had been planted too deep.

After two growing seasons each survivor was examined to determine the proportion of its 1970 foliage that was infected or destroyed by brown spot. Estimates were made to the nearest 10 percent except that seedlings regarded as resistant--i.e., those with 5 percent or less needle loss--were estimated to the nearest 1 percent. Seedling heights were recorded to the nearest 0.1 foot. These data were analyzed for differences among families in:

Average percent of diseased needle tissue

Proportion with 5 percent or less infection
(Freeman-Tukey arcsine transformation)

Proportion surviving (F-T transformation)

Average height

Similar analyses were made for geographic differences; in these analyses States, or location within State in the case of Alabama, were taken as sources.

All tests of significance were at the 0.01 level.

RESULTS

After 2 years of field exposure, the half-sib families differed widely in percentage of needle tissue dead or infected, in proportion of seedlings with needle loss of $\leq$ 5 percent, and in survival and average height (table 1).

Table 1.--Means, ranges, and variances from analyses of 227 wind-pollinated longleaf pine families screened for brown-spot resistance after 2 years of field exposure

Variable	Mean	Range	Error M.S.	Family M.S.	
Average percent diseased	26	4-59	151.9537	536.4150	(significant)
Proportion with $\leq$ 5 percent infection	37	2-89	196.8594	570.0343	(significant)
Proportion surviving	88	56-100	80.4805	483.7500	(significant)
Average height (feet)	0.43	0.22-.76	2.0153	3.8243	(significant)

D.F. Families = 226 Error = 675 (3 missing plots subtracted)

Brown-Spot Resistance

Brown-spot build-up followed a pattern that has been familiar within the general area of the test site. Seedlings remained relatively free of disease through the first year. Infection developed rapidly in the second year, reaching a mean rate of 26 percent needle loss for all progenies combined. Since spread of infection is never uniform, there is always some doubt whether clean seedlings are resistant or escapes. In many instances, however, relatively clean plots (60-foot rows) were bordered by heavily infected plots. Since brown spot normally spreads concentrically, this pattern indicates fairly adequate exposure.

The best and the poorest 10 percent of the progenies are listed in table 2. Ranking is based primarily on the proportion of survivors with 5 percent or less needle infection, although the relationship between this statistic and the conventional expression of brown-spot severity--average percent of current needle involvement--is close. In the best 10 percent--22 families--72 percent of the survivors were classified as resistant ($\leq$ 5 percent infection), and the amount of diseased needle tissue averaged 11 percent. In the poorest, or most susceptible, group of 22 families only 8 percent of the survivors were resistant, and loss of current needle tissue averaged 48 percent. Survival of the two groups was nearly alike. Extremes in individual family performance are represented by a South Carolina parent with nearly 90 percent of its progeny classed as resistant, and a Louisiana tree with only 2 percent.

Wind-pollinated seedlings from Siggers' resistant genotype have been planted in many earlier tests, and have consistently yielded 30-40 percent resistant individuals under conditions where nonresistant stock has failed entirely. They performed similarly in the current study; 45 percent were classed as resistant. However, this tree ranked only 78th in the array of 227 means, and it was exceeded by one other Louisiana tree.

Geographic influences are fairly evident in table 2. Parent trees in Alabama, South Carolina, and Florida dominate the most resistant group, while those with least resistance are largely from Louisiana and Texas. Analyses of State means revealed significant differences in all variables tested (table 3). Progenies originating in south Alabama (Conecuh National Forest) excelled all others in resistance, and those from the eastern part of the range, with the exception of North Carolina trees, excelled the local Louisiana source by a 2 to 1 margin.

Families within a State source varied considerably. For example, 51 percent of the progenies from south Alabama trees and 45 percent of those from north Alabama were resistant, but the range for all sources within the State was 12 to 89 percent. The poorest source, Louisiana, averaged only 20 percent resistant, but the parents varied from almost completely susceptible (2 percent) to 62 percent resistant.

Survival and Growth

Survival varied among progenies and geographic sources. However, it is doubtful if the differences have practical significance, since a large but undetermined fraction of the loss was caused by pocket gophers.

Table 2.--Ten percent of 227 longleaf pine half-sib families having highest resistance to brown-spot infection in a central Louisiana test, compared with 10 percent having lowest resistance

Parent tree	Most resistant				Parent tree	Least resistant			
	Survivors with ≤ 5 percent infection	Average diseased needles	Survival	Average height		Survivors with ≤ 5 percent infection	Average diseased needles	Survival	Average height
	Percent	Percent	Percent	Feet		Percent	Percent	Percent	Feet
So. Car. 202	89	4	95	0.51	La. 237	2	47	90	0.36
Ala. Con 100	84	8	87	.63	La. 279	3	54	90	.43
Ala. Tal 95	83	6	90	.51	La. 143	3	57	95	.52
Miss. Bx 20	78	9	77	.56	Texas 264	4	57	87	.26
So. Car. 57	78	9	92	.58	La. 130	4	49	69	.27
Ala. Con 68	78	9	92	.44	La. 253	5	49	92	.37
Ala. Con 61	76	10	82	.37	Texas 276	6	57	97	.34
Fla. 129	75	6	92	.76	La. 441	6	55	97	.36
So. Car. 100	73	9	85	.43	La. 412	6	48	95	.39
Ala. Tal 34	72	11	77	.41	La. 450	6	42	85	.48
Ala. Tal 165	71	11	87	.51	Texas 9	8	49	90	.39
Fla. 21	69	8	90	.32	Texas 270	9	46	87	.56
Ala. Tal 78	68	12	87	.44	Texas 273	9	52	93	.45
Ala. Con 47	68	14	95	.37	No. Car. 1006	9	44	60	.29
So. Car. 128	67	13	90	.56	Texas 321	10	46	92	.52
So. Car. 86	67	11	80	.33	Texas 341	11	43	90	.54
Fla. 93	67	13	87	.35	Miss. Bx 25	11	39	88	.61
Ala. Con 36	66	12	97	.47	Texas 76	11	39	84	.52
So. Car. 176	64	12	87	.40	No. Car. 43	11	40	92	.40
La. 149	62	15	82	.43	La. 238	12	45	80	.37
Ala. Tal 160	62	17	92	.32	Ala. Con 4	12	39	85	.35
Texas 358	62	19	56	.41	Fla. 284	18	59	82	.33
Group mean	72	11	86	.46		8	48	87	.41
Grand mean	37	26	88	.43		37	26	88	.43

Table 3.--Means of progenies grouped by State of origin, and analyses of geographic source differences

Geographic source	Survivors with $\leq$ 5 percent infection	Average diseased needle tissue	Survival	Average height
	Percent	Percent	Percent	Feet
Alabama--south	51	18	88	0.42
Alabama--north	45	20	90	.41
South Carolina	45	21	89	.44
Florida	44	20	85	.46
Mississippi	37	25	90	.45
North Carolina	27	33	84	.36
Texas	27	32	86	.49
Louisiana	20	38	86	.40
Mean	37	26	87	.43

Analyses of Variance--Geographic Sources

Variable	Error M.S.	Source M.S.
Proportion with $\leq$ 5 percent infection	7.0927	186.5058 (significant)
Average percent diseased	7.3129	221.2166 (significant)
Survival	4.1084	16.3195 (significant)
Average height	0.0894	0.7193 (significant)

D.F. Error = 21 Source = 7

Average seedling heights differed significantly among progenies at age 2; they ranged from 0.21 to 0.76 foot. Differences among the geographic sources also were significant, but the range was considerably less. The most vigorous progenies were well into active height growth at the end of 2 years, with little within-plot variation among individuals. Others displayed considerable variation in height initiation, while some were uniformly stemless. Progenies with low brown-spot infection generally grew best, but there were some exceptions. For example, two families with exceptionally light infection ranked 45th and 46th in the array of height means. Also, progeny of the Texas trees were the tallest among the eight geographic sources but ranked high in brown-spot susceptibility.

DISCUSSION

The superior-tree selections have yielded a higher ratio of brown-spot resistant trees than any group previously tested. Seventy-seven of the 227 parents ranked ahead of Siggers' tree. This performance exceeds previous results by a wide margin. If only trees growing west of the Mississippi River are considered, seven of 75 parents can be classified as resistant. This, too, is above the average for a routine screening test. So it can be concluded, tentatively, that a dominant tree, selected for superior growth and form, is somewhat likely to have brown-spot resistance.

Geographic differences, or in this test superiority of nonlocal sources, confirm earlier studies in indicating an east-to-west gradient in brown-spot susceptibility, especially for the Gulf Coast States (Henry and Wells 1967). The Louisiana trees as a group did not perform well in this study. When central Louisiana trees have been planted elsewhere, as in the Southwide Pine Seed Source Study, their survival has been good but their growth has been slowed by brown spot (Wells and Wakeley 1970). The current study points out, as others have, the superiority of south Alabama sources.

Mass screening under field conditions is the only method now available for detecting brown-spot resistance in longleaf pine. While laborious, it is apparently effective since all tests completed to date have shown wide variation in susceptibility among half-sib families. Some retesting has been done to confirm earlier results. One such test was made concurrently with this study, on the same site and with identical procedures. It included wind-pollinated seedlings from 80 Louisiana selections gleaned from earlier screening tests. Average needle loss of the 80 selections was 17 percent, and 56 percent were classed as resistant. Comparable values for the superior-tree selections were 26 percent needle loss and 37 percent resistant.

LITERATURE CITED

Derr, H. J., and Melder, T. W. 1970. Brown-spot resistance in longleaf pine. Forest Sci. 16: 204-209.

Henry, B. W., and Wells, O. O. 1967. Variation in brown-spot infection of longleaf pine from several geographic sources. USDA Forest Serv. Res. Note SO-52, 4 pp. South. Forest Exp. Stn., New Orleans, La.

Siggers, P. V. 1944. The brown spot needle blight of pine seedlings. USDA Tech. Bull. 870, 36 pp.

Verrall, A. F. 1934. The resistance of saplings and certain seedlings of *Pinus palustris* to *Septoria acicola*. Phytopathology 24: 1262-1264.

Wakeley, P. C. 1970. Thirty-year effects of uncontrolled brown spot on planted longleaf pine. Forest Sci. 16: 197-202.

Wells, O. O., and Wakeley, P. C. 1970. Variation in longleaf pine from several geographic sources. Forest Sci. 16: 28-42.

Predictions of Expected Gains in Resistance to Fusiform Rust in Loblolly Pine

By

Roger L. Blair and Bruce J. Zobel[1]

Although properly timed fungicidal sprays are effective in control of fusiform rust in forest nurseries, no economical chemical or silvicultural method of control has been developed to control the disease in plantations. The most promising mode of defense against future losses to this disease is the selection, breeding, and wide-spread distribution of genetically resistant strains of loblolly and slash pines.

Since the causual organism of fusiform rust (Cronartium fusiforme Hedgc. and Hunt ex cumm.) and both loblolly and slash pine (Pinus taeda L. and P. elliottii Engelm. var. elliottii) are indigenous to the same region, it is likely that genetically controlled resistance to rust has evolved in both species of trees. A number of studies have shown that variability in resistance does exist in both loblolly (Kinloch and Stonecypher, 1969; Woessner, 1965; Wells and Wakeley, 1966) and slash pine (Barber, 1964; Goddard and Arnold, 1966; Gansel, et al., 1971). The utilization of this variability depends upon: (i) the degree of additive genetic control of resistance, (ii) the stability of resistance over a range of environments, (iii) the genetic correlations between resistance to rust and other economically important traits, and (iv) the type of breeding program undertaken to provide rust-resistance.

Since genetically controlled resistance to fusiform rust is of major economic value in the Southeast, most tree improvement programs in this region include rust-resistance as an important trait. Accurate estimates of the genetic parameters that describe rust-resistance are required as the basis for the integration of this trait into a breeding program. The present investigation was designed (i) to estimate the degree of genetic control of variability in rust-resistance in a natural stand of loblolly pine and (ii) to predict the gain in resistance that can be expected from the methods of selection commonly used in tree breeding programs.

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[1] Research Forester, International Paper Company, Southlands Experiment Forest, Bainbridge, Georgia, and Professor, Forest Genetics, North Carolina State University, Raleigh, North Carolina, respectively.

MATERIALS AND METHODS

The population of plants used in this investigation is found in the Loblolly Pine Heritability Study carried out cooperatively by International Paper Company and North Carolina State University. The study is located in Decatur County in Southwest Georgia on International Paper Company's Southlands Experiment Forest. Detailed description of the parent trees, mating design, planting design, and outplanting sites was given by Stonecypher (1966). Further description of the study with respect to fusiform rust was provided by Kinloch and Stonecypher (1969); therefore, only the following brief summary will be included in this paper.

Parent Trees

The loblolly pine parent trees were selected at random in a mixed stand of native loblolly with intermixed shortleaf (*P. echinata* Mill.) and a few longleaf pines (*P. palustris* Mill.). Even though located in the Coastal Plain, the trees are growing on a site which has soil and vegetation typical of the southern Piedmont. Much of the area was under cultivation until the 1920's and early 30's. The stand from which the parent trees were chosen originated from seeds from trees surrounding abandoned cultivated fields. The parent trees averaged thirty-five years of age when the study was initiated in 1959. With aid of binoculars, fusiform rust galls were counted on the branches and stem of each tree.

Mating Design

Controlled matings were made among the parent trees according to Comstock and Robinson's (1948, 1952) Design I. Sixty-five male groups were randomly chosen from the parent trees. Each group consisted of a pollen parent (male) that was mated to each of four nearby seed (female) parents. Control-pollinations within male groups were carried out over a three-year period (from 1959 to 1961).

Nursery Treatment and Field Planting Design

Seeds from the controlled matings were collected and planted in nursery beds at Southlands Experiment Forest in 1962-64. Fusiform rust infection was not controlled in the nursery, therefore, some seedlings that were infected while in the nursery were planted in the field. Otherwise, the seedlings were grown using normal nursery procedures.

The seedlings from each control-pollinated family were planted with 12 trees in each of six row-plots. The six plots were distributed in three replications at each of two locations. Field planting was carried out over a three year period beginning in January 1963; each year's planting consisted of a different group of families. The trees were established at an 8' x 8' spacing. Because of the large number of families involved, male groups were confounded in sets to reduce the size of each replication. Since not all matings produced enough viable seeds, two of the three plantings contained unequal numbers of male groups and females per male group.

Planting Sites

Southlands Experiment Forest is divided by the Flint River into two parts which are very different. However, the sites in which the control-pollinated portion of the study were planted differed mainly in previous cultural history. The site east of the river (east planting) supported a sparse stand of loblolly and shortleaf pine which was removed and the site prepared by treatment with a rolling chopper and disk. This site is less uniform than the planting site west of the river. During extended periods of wet weather, water stands in the low areas. These areas were avoided during planting so that certain sets were not contiguous within some replications.

Most of the area west of the river (west planting) had been cultivated to peanuts immediately prior to planting, but one replication of the 1963 planting had lain fallow several years prior to 1963. The difference in amount of rust in these replications is discussed in detail by Kinloch and Stonecypher (1969).

Measurement of Rust Susceptibility

In 1967 and again in 1968 each tree in the 1963 and 1964 plantings was examined for fusiform rust galls. The amount of rust was measured by three indices of susceptibility: (i) the number of rust galls per tree, (ii) "c-score," and (iii) the percentage of trees infected. Part of the 1968 measurement was made during the early spring when the rust galls were sporulating and thus easily visible. This measurement was thus more reliable and was used in the following analyses.

Separate records were made of the number of stem galls, branch galls considered likely to grow into the stem, and branch galls considered unlikely to grow into the stem before the branch died. Only the total number of galls per tree was used for the following analyses.

"C-score" is an index devised by personnel at Southlands to reflect the economic and biological impact as well as the incidence of disease. Numerical values were assigned as follows:

1 = no galls
2 = branch galls
3 = severe branch galls
4 = one stem gall
5 = two or more stem galls
6 = one stem gall and branch galls (4 and 2)
7 = one stem gall and severe branch galls (4 and 3)
8 = two or more stem galls and branch galls (5 and 2)
9 = two or more stem galls and severe branch galls (5 and 3)
10 = dead because of rust infection or with multiple stems as a result of severe rust infection

The last score (No. 10) also includes all trees which had rust at an earlier date but were missing at the time of the 1968 measurement. The scorer was required to decide subjectively whether or not branch galls were severe (scores 2 or 3 and 8 or 9) and whether the tree had multiple stems because of rust infection.

The percentage of infected trees per plot was calculated based on the c-score data: *i.e.* all trees with a score greater than one were considered infected. It also includes all trees having been recorded as diseased in earlier measurements even though the tree may have been missing or evidence of rust infection may no longer have been present at the 1968 measurement. The raw percent data were transformed to arcsins of the square root of the percentage of infected trees. The transformed data were used for all analyses except gain computations.

Analysis

The form of analysis of variance, tests of significance and estimates of components of variance and their standard errors, are described in detail elsewhere (Blair, 1970). Estimates of heritability (on an individual tree basis) were computed for the c-score and number of galls per tree indices utilizing components of variance as estimates of the genetic parameters. For the percent infected index, Robertson and Lerner's (1949) method for all-or-none traits was employed.

Predicted gains were computed from the estimated genetic parameters using three systems of selection. The first was based on the mass selection of rust-free trees. Resistance to rust as measured by the percentage of trees infected is considered a threshold trait in the method presented by Dempster and Lerner (1950) and progress in achieving resistance is obtained by selecting all or a random sample of rust-free parent trees and using them to produce the next generation.

Gains in resistance to rust from mass selection as measured by the number of galls per tree and c-score indices were computed by conventional gain prediction formulae (see Namkoong et al., 1966). Again, only rust-free parent trees are selected and used to produce the next generation.

The second system of selection involved mass selection combined with progeny testing. Mass selection is carried out as above i.e., rust-free male parent trees are selected. The half-sib progeny from each of the selected trees is then used as a basis for further selection. Approximately half of the parent trees were culled on this basis.

If mass selection and mass selection combined with progeny testing produce gains in resistance in the first generation of progeny from selected trees, continued selection among first generation progeny -- both among and within families -- should produce increased resistance in the second generation (Stonecypher, 1969). In this study each male parent was mated to a series of female parents producing full-sib families. Consequently, gain predictions were based on selection among and within full-sib families. Since recombination has occurred in production of the first generation progeny, the genetic variation was assumed to be reconstituted. The parameters estimated for the first generation were then used in the prediction formula (modified from Namkoong et al., op. cit.) to estimate the gains in resistance that might be expected when using progeny tests as a source of second generation selections.

RESULTS AND DISCUSSION

The results of this study support the following conclusions:

1. Substantial variation in resistance to fusiform rust in loblolly pine as reported in earlier studies are confirmed. In the population used in this investigation, resistance to fusiform rust in loblolly pine is under moderate to weak genetic control.

2. Selection of uninfected parent trees from natural stands will yield an important initial gain (approximately fifteen percent of the mean) in resistance to fusiform rust. Selection based on subsequent progeny testing will yield an additional gain of similar magnitude (between fifteen and twenty percent of the mean). It is essential to combine mass selection and progeny testing if maximum progress is to be obtained in the first generation of selection.

3. Family plus within-family selection will result in substantial improvement in rust-resistance and is recommended for second generation selection.

Variation in Resistance to Rust

Great variation in resistance to fusiform rust was observed by all indices of susceptibility on both planting sites and in both years of planting (Table 1). Differences between the most resistant and most susceptible families (8 percent infected vs. 91 percent infected) were greater than differences among provenances in any of the planting locations of the Southwide Pine Seed Source Study (Wells and Wakeley, 1966). This comparison emphasizes the importance of within-stand variation in the search for rust-resistance.

Table 1. Variation in amount of fusiform rust measured by the three indices of susceptibility. The data given are means and ranges for the families included in each year of planting

Year of Planting	West Location		East Location		Locations Combined	
	Mean	Range	Mean	Range	Mean	Range
			Number of Galls Per Tree			
1963	2.7	0.3-9.0	0.8	0.0-3.4	1.7	0.2-6.2
1964	1.6	0.3-3.3	0.5	0.0-1.4	1.0	0.3-2.3
	2.1		0.6		1.4	
			C-Score			
1963	4.0	1.2-7.4	2.0	1.1-4.7	3.0	1.2-6.0
1964	2.8	1.4-5.3	1.6	1.0-2.9	2.2	1.3-4.0
	3.4		1.8		2.6	
			Percent of Trees Infected			
1963	66	8-100	34	5-58	50	8-91
1964	57	13-90	25	0-68	41	13-79
	62		30		46	

The degree of additive genetic control in rust-resistance ranged from moderate to weak, depending on the index and year of planting being considered (Table 2). Heritabilities on an individual tree basis were computed for the number of galls per tree and c-score using components of variance and for the percentage of trees infected using Robertson and Lerner's (1949) approach.

The heritability estimates for the combined locations for the number of galls per tree, c-score, and percentage of trees infected were 0.29, 0.22, and 0.20 respectively for the 1963 planting and 0.09, 0.04, and 0.12 for the 1964 planting. These estimates are remarkably consistent among indices, particularly considering the different methods of computation. The heritability estimates for the percentage of trees infected also agree very well with the 0.199 estimate reported by Goddard and Arnold (1966) for slash pine.

Table 2. Estimates of heritability (individual tree basis) and standard errors for resistance to fusiform rust. Shown for two planting years and three indices of susceptibility

	INDEX		
Year of Planting	No. Galls	C-Score	% Infected
1963	.29 ± .13	.22 ± .09	.20 ± .05
1964	.09 ± .06	.04 ± .03	.12 ± .03

It is important to note that estimates obtained for the percent infected index include a certain portion of non-additive variance (Dempster and Lerner, 1950) so is not strictly comparable to the gall count and c-score. The comparison of these estimates in the 1963 planting suggests that genetic control is strictly additive while the 1964 planting would appear to have some non-additive genetic variance. The comparisons of heritabilities in this manner are somewhat tenuous, however, in view of the large standard errors of estimates of the components of variance used in their estimation.

The heritability estimates based on an individual tree are not unexpectedly low and are encouraging in the framework of existing selection programs.

Predictions of Gain

Gain from the Selection and Mating of Rust-Free Individuals

In the absence of better information, the logical procedure for breeding for rust-resistance is the selection and mating of rust-free trees. In the study reported here, a grouping of progenies by the mating type of their parents (Table 3) shows that mating rust-free with rust-free individuals varies from no increase in resistance to thirty-eight percent of the mean depending upon the index of susceptibility and year of planting.

An examination of the results of mass selection and progeny testing can be carried out with the combined plant material of the 1963 and 1964 plantings. The following assumptions must first be made:

1. The 37 male parents of the trees in the two years' plantings constitute a population from which selection for rust-resistance is proposed.
2. The combined control-pollinated progenies of each male group approximate a wind-pollinated progeny test.
3. The progeny from the 1964 planting can be made comparable to the progeny of the 1963 planting by a simple addition of the difference between the means of the two years' plantings to the 1964 progeny means.
4. Saving 50 percent of the selected parents constitutes a reasonable culling level based on progeny test information.

Of the 37 male trees, 11 are rust-free and thus qualify for mass selection. These selected male groups have means of 1.49, 2.73, and 45 percent for number of galls per tree, c-score, and percentage of trees infected, respectively (Table 4, Part A). The means of all families in the 1963 planting were 1.73, 2.95, and 49 percent, respectively (see Tables 1 and 4); thus, a small gain for each index (0.24, 0.22, and 4 percent) was realized through selection of uninfected parent trees. Selection of the five "best" males of this group based on the means of their progeny, however, showed a larger increment of gain (Table 4, Part A). The additional gain due to progeny testing in units of the three indices of susceptibility was 0.49 for number of galls per tree, 0.50 for c-score, and 9.4 for the percentage of trees infected. The importance of progeny testing is reflected in an examination of the trees rejected because of poor progeny performance. Trees 20 and 39 would be chosen as rust-free phenotypes (Table 4, Part A). Their progeny, however, were greatly inferior by all three indices of susceptibility and the rejection of these two trees is essential if substantial gain in rust-resistance is to be made in the first generation of selection.

Table 3. Means[a] and differences from grand means[b] of families recorded by the phenotype of their parents (type of mating) and summarized by year of planting and index of susceptibility

Type of Mating	1963 Planting No. Of Families	1963 Planting Mean	1963 Planting Difference from Grand Mean	1963 Planting % Change in Mean	1964 Planting No. Of Families	1964 Planting Mean	1964 Planting Difference from Grand Mean	1964 Planting % Change in Mean
		Number of Galls Per Tree						
		Grand Mean = 1.73				Grand Mean = 1.01		
Rust-free x rust-free	6	1.08	-0.65[c]	-38%	13	0.88	-0.13	-13%
Rust-free x infected	34	1.46	-0.27	-16%	30	0.93	-0.08	- 8%
Infected x infected	34	2.12	+0.39	+23%	17	1.22	+0.21	+21%
		C-Score						
		Grand Mean = 2.95				Grand Mean = 2.24		
Rust-free x rust-free	6	2.17	-0.78	-26%	13	2.04	-0.20	- 9%
Rust-free x infected	34	2.78	-0.17	- 6%	30	2.07	-0.17	- 8%
Infected x infected	34	3.26	+0.31	+11%	16	2.57	+0.33	+45%
		Percentage of Trees Infected						
		Grand Mean = 49%				Grand Mean = 41%		
Rust-free x rust-free	6	32%	-17%	-35%	13	41%	0%	0%
Rust-free x infected	34	45%	- 4%	- 8%	30	38%	-2%	- 5%
Infected x infected	34	56%	+ 7%	+14%	16	46%	+5%	+12%

[a] Mean susceptibility for a given mating type

[b] Mean for all families taken together for a given year of planting

[c] Minus indicates increase in resistance compared to the mean

Table 4. Means[a] of the half-sib progeny of trees selected as "best" on the basis the trees' phenotype and its half-sib progeny performance

Male Tree	Half-Sib Progeny Mean No. Galls	 C-Score	 % Infected
Part A -- Trees selected because they were rust-free. Best five chosen on the basis of progeny performance			
10	0.61*[b]	1.67*	28*
3	1.03*	2.06*	34*
19	1.34*	2.42*	40*
22	1.31*	2.50*	38*
50	0.73*	2.52*	38*
14	1.49	2.65	44
12	1.63	2.77	42
30	1.71	2.99	50
42	1.90	3.21	56
39	2.25	3.54	66
20	2.47	3.67	63
Overall Mean	1.49	2.73	45
Mean of Best Five	1.00	2.23	35.6
Part B -- Trees selected on the basis of progeny performance only			
10	0.61**[c]	1.67**	28**
3	1.03**	2.06**	34**
1	1.14**	2.30**	43
21	0.96**	2.36**	44
19	1.34	2.42**	40**
22	1.31	2.50	38**
50	0.73**	2.52	38**
Mean of Best Five Male Trees	0.89	2.16	35.6

[a] The male group means from the 1964 planting have been adjusted so as to be comparable to the 1963 planting means. This has been accomplished by adding the difference between the two years of planting (9 percent for the percent infected index) to the 1964 male group means.

[b] Best five (based on progeny performance); (*)

[c] Male trees selected as best for each index; (**)

The suggestion has often been made that in selecting only rust-free phenotypes for use in a tree improvement program, the tree breeder may be rejecting many otherwise excellent phenotypes because they have only minor rust infection. The belief has been expressed that many of these rejected trees are likely to produce progeny that would be as resistant as the progeny of rust-free trees. To test this hypothesis, five male trees with the least severely infected progeny were chosen regardless of the phenotype of the male parent itself (Table 4, Part B). For the percentage of trees infected, the same five male trees (Nos. 10, 3, 19, 22, and 50) were chosen on the basis of progeny performance as were chosen when the 11 rust-free male trees were selected and only these rust-free trees progeny tested. For c-score and number of galls per tree, male trees 1 and 21 were included among the five best (their progeny were among the least infected), although both had minor rust infection. It is important to note that their inclusion resulted in a reduction of rust severity over the five rust-free selections of only 0.11 galls per tree and 0.07 c-score units. Thus, for all three indices the initial selection of rust-free trees greatly reduced the number of trees to be progeny tested without seriously affecting the ultimate gain in resistance (see Table 4). No exceptionally good genotypes were rejected by mass selection as was the case in height growth for longleaf pine (Snyder, 1969).

It is apparent, however, that some infected x infected matings and many more rust-free x infected matings were less severely infected than the mean (Table 3). Evidence has been reported that suggests that techniques of artificial inoculation (Dinus, 1969) may soon allow the rapid identification of rust-resistant genotypes without long term field testing. This would allow selection for rust-resistance to proceed regardless of the phenotype of the candidate tree and at a more rapid rate than is possible in field testing. However, until the methods of artificial inoculation have become more adequately tested and until their relationship to field infection has become confirmed, including infected trees in a selection program should be avoided.

Predicted Gains

One of the objectives of this study was to predict the gain to be expected from different selection procedures. Because of the large differences in estimates of components of variance between the years of planting, the parent trees from each year were regarded as separate populations in these gain estimations; predicted gains were computed accordingly. A procedure similar to that followed in the construction of Table 4 was used; the 22 male trees of the 1963 planting and the 15 males of the 1964 planting comprised the populations in which selection took place. The families that resulted from the mating of the selected (rust-free) males with the rust-free females in their respective male groups were used as the basis for progeny testing the original selections. Since only rust-free x rust-free matings were included in the progeny testing, the progeny approximate those resulting from wind-pollination in a seed orchard consisting of rust-free selections.

The computation of predicted gain was carried out using the selection intensities dictated by the procedure described above. The 1963 planting consisted of 22 male parents, only four of which were rust-free, while the 1964 planting had 15 male parents, seven of which were rust-free. Approximately 50 percent of the selected parent trees were then culled on the basis of the performance of their progeny. Of the four selections in the 1963 planting, two were culled, while three of the seven selections in the 1964 planting were culled.

The predicted gains following these criteria (using the selection intensities shown above and the estimated components of variance for each year) are summarized for all three indices of susceptibility in Table 5, Parts 1 and 2. Gains are presented in units of the index of susceptibility and as a percent of the mean (the average of all families taken together for each year of planting).

The value of progeny testing is demonstrated by these gain predictions. Since the objective of progeny testing is to remove a relatively few poor performers, the selection intensities used in gain computations were low. In spite of this, the realized gain expressed as a percent of the mean is at least doubled in nearly every case by the addition of progeny testing to mass selection; therefore, the additional effort required to progeny test appears to be well worthwhile.

Predicted gains are much lower for the 1964 planting than the 1963 planting (Table 5) reflecting the difference in inheritance patterns. Additive genetic variation, hence general combining ability, was utilized in the selection procedures presented above. The parents of the 1963 planting contained males with good general combining ability, thus selection would be relatively successful in this population. The parent trees of the 1964 planting, on the other hand, showed a great deal more specific combining ability. The progeny reacted unexpectedly to exposure to rust. Rust-free male trees in certain specific crosses with the rust-free females occasionally produced progenies which were severely infected.

Family Plus Within-Family Selection

The methodology and effectiveness of the first generation of a tree breeding program influences subsequent progress; therefore, consideration must be given in the first generation to the procedures planned for later generations. In an examination of recurrent selection as applied to forest trees, Stonecypher (1969) presented analyses based on third-year height growth which showed that a combination of family plus within-family selection produced good results. This selection procedure was applied to the data from this study to give an indication of the progress that might be expected from second generation selection for resistance to fusiform rust (Table 4, Part 3). The selection intensity for the family selection stage was equal to selecting 11 of the 134 full-sib families

Table 5. Predictions of gain using three methods of selection and three indices of susceptibility

	Predicted Gain			
	In Index Units		In % Of Mean	
	1963	1964	1963	1964
1. Mass Selection				
Gall Counts	0.97	0.09	56%	9%
C-Score	0.71	0.07	24%	3%
Percent Infected (as threshold trait)	8%	4%	16%	9%
2. Mass Selection + Progeny Testing				
Gall Counts	1.67	0.25	91%	25%
C-Score	1.40	0.26	47%	12%
Percent Infected	18%	8%	36%	18%
3. Family + Within-Family				
Gall Counts	1.69	0.46	98%	46%
C-Score	0.88	0.37	30%	17%

in both planting years. The intensity used for within-family selection was based on the assumption that the best individual in each family (judged on the basis of its performance corrected for replication effect) would be chosen for use in a second generation seed orchard. Therefore, based on the conservative estimate that each family was represented by a total of 48 individuals over the six replications in the study, a selection intensity of 1 in 48 would result. Even the most severely infected of the best 11 families would probably not have more than 20 percent of its members infected with rust. Therefore, of the 48 individuals in each family, 38 would be rust-free so that within-family selection would result in the random choice (if resistance to rust is the only trait under selection) of one of the 38 rust-free individuals. The effective selection intensity was 38 out of 48 even though only one individual would actually be selected.

The following factors must be considered when interpreting the results of the family plus within-family selection procedure. First, the selection scheme utilized variance components estimated from a highly variable, unselected population. Since a second generation scheme as considered here would be applied to a selected and progeny tested population, the components of variation may be over-estimated when used for predictive purposes. The importance of these over-estimations would depend upon the intensity of the selection that took place in the first generation, but probably would not be serious in that the first generation selection intensities were relatively low. Secondly, the distributions of the number of galls per tree and c-score are skewed to the right and have lower limits of one and zero, respectively. The non-normality of these distributions probably would cause an over-estimation of the gain to be expected from selection designed to increase resistance; i.e., move the mean toward one or zero. Such an over-estimation would make complete resistance appear more easily attainable than it probably is (note the gain of 98 percent of the mean predicted for the gall count index, Table 4, Part 3).

Consideration of these factors is important in the appraisal of the predictions of gain for family plus within-family selection. Gains in c-score were 30 and 17 percent of the mean for the 1963 and 1964 planting, respectively, while the number of galls per tree showed gains of 98 and 45 percent. Such gains can be interpreted as an indication that this method of selection will result in continued progress in attaining rust-resistance but should not be considered as exact predictions of expected progress.

Implications for an Applied Breeding Program

A number of reports have shown that the variability in resistance to rust is wide-spread. These reports have ranged from the intensive sampling of a single stand in this study to the region-wide sampling of the Southwide Pine Seed Source Study. The conclusion (Barber, 1966) that inherent variation in resistance is probably widely distributed throughout the Southeast has been substantiated by this and other reports1/. In addition to the obvious importance of the existence of sufficient variation to allow selection to be successful, the existence of local variability indicates that the tree breeder can select for resistance within a seed source adapted to grow best under local conditions.

The additive genetic control of resistance estimated on an individual tree basis was lower than desirable for rapid advances from mass selection alone. The estimated gains when combining mass selection and progeny testing, however, are encouraging.

The indication of probable continued improvement through family plus within-family selection in the second generation suggests that two generations of selection may well decrease fusiform rust to an amount that can be tolerated on all but sites with the most severe rust hazard. This projection, of course, excludes the possibility of any unforeseen change in the host-parasite relationship.

1/ Several examples based on extensive progeny tests are given in the Thirteenth Annual Report, N. C. State University-Industry Cooperative Tree Improvement Program. May 1969, pages 9-13.

LIST OF REFERENCES

Barber, J. C. 1964. Inherent variation among slash pine progenies at the Ida Cason Callaway Foundation. U. S. Dept. Agr. Forest Service, Southeast. Forest Expt. Sta. Res. Paper SE-10, Asheville, N. C. 90 pp.

Barber, J. C. 1966. Variation among half-sib families from three loblolly pine stands in Georgia. Ga. For. Res. Council, Paper No. 37, Macon, Ga. 5 pp.

Blair, R. L. 1970. Quantitative inheritance of resistance to fusiform rust in loblolly pine. Ph.D. Thesis. 86 pp. N. C. State Univ., Raleigh, N. C.

Comstock, R. E., and H. F. Robinson. 1948. The components of genetic variance in populations. Biometrics 4:254-266.

Comstock, R. E., and H. F. Robinson. 1952. Estimation of average dominance of genes, pp. 494-516. In J. W. Gowen (ed.), Heterosis. Iowa State College Press, Ames, Iowa.

Dempster, E. R., and I. M. Lerner. 1950. Heritability of threshold characters. Genetics 35:212-236.

Dinus, R. J. 1969. Testing slash pine for rust resistance in artificial and natural conditions. Proc. Tenth South. Conf. on Forest Tree Improvement. pp. 98-106.

Gansel, C. R., R. H. Brendemuehl, E. P. Jones, Jr., and J. W. McMinn. 1971. Seed source effects in 5- and 10-year-old test plantings of slash pine in Georgia and Florida. Forest Sci. 17:23-30.

Goddard, R. E., and J. T. Arnold. 1966. Screening select slash pines for resistance to fusiform rust by artificial inoculation, pp. 431-435. In H. D. Gerhold, E. J. Schreiner, R. E. McDermott and J. A. Winieski (eds.) Breeding Pest-Resistant Trees. Pergamon Press, N.Y.

Kinloch, B. B., and R. W. Stonecypher. 1969. Genetic variation in susceptibility to fusiform rust in seedlings from a wild population of loblolly pine. Phytopath. 59:1246-1255.

Namkoong, G., E. B. Snyder, and R. W. Stonecypher. 1966. Heritability and gain concepts for evaluating breeding systems such as seedling orchards. Silvae Genet. 15:76-84.

Robertson, A., and I. M. Lerner. 1949. The heritability of all or none traits: viability of poultry. Genetics 34:395-411.

Snyder, E. B. 1969. Parental selection versus half-sib family selection of longleaf pine. Proc. Tenth South. Conf. Forest Tree Improvement: 84-88.

Stonecypher, R. W. 1966. The loblolly pine heritability study. Southlands Experiment Forest Tech. Bul. No. 5, International Paper Co., Bainbridge, Georgia. 128 pp.

Stonecypher, R. W. 1969. Recurrent selection in forest tree breeding. Proc. Tenth South. Conf. Forest Tree Improvement: 7-16.

Wells, O. O., and P. C. Wakeley. 1966. Geographic variation in survival, growth, and fusiform rust infection of planted loblolly pine. Forest Science Monograph 11. 40 pp.

Woessner, R. A. 1965. Growth, Form and disease resistance in four-year-old control and five-year-old open-pollinated progeny of loblolly pine selected for use in seed orchards. School of Forestry, Tree Improvement Program Tech. Rept. No. 28, N. C. State Univ., Raleigh, N. C. 67 pp.

PHENOTYPIC SELECTION FOR FUSIFORM RUST RESISTANCE

R. J. Dinus[1]

Abstract.--Open-pollinated progenies from fusiform-rust-free slash pines selected in a 94-percent infected plantation in Mississippi were all more resistant to artificial inoculation than seedlings from a bulk seed lot. Only one rust-infected parent transmitted any appreciable degree of resistance to its progeny.

Phenotypic selection in heavily infected stands seems an efficient method for finding sources of resistance. Variability among progenies of rust-free parents was sufficient to permit additional gain from culling after progeny testing.

Fusiform rust, caused by Cronartium fusiform Hedgc. and Hunt ex Cumm., remains a serious disease of loblolly (Pinus taeda L.) and slash pines (P. elliottii Engelm.). Most tree-improvement programs in the Southeast attempt to increase resistance to this disease by avoiding the selection of rust-infected trees. The efficiency of this practice depends upon the amount of variation in resistance available to breeders and the degree to which a rust-free phenotype reflects the presence of heritable resistance.

Substantial variation in resistance under field conditions has been observed in loblolly (Barber 1966) and slash pines (Barber 1961). Variation in resistance to infection after artificial inoculation has also been reported for both species (Davis and Goggans 1968; Jewell and Mallett 1967). On the other hand, the selection and breeding of plus trees free of rust has often failed to appreciably increase resistance (North Carolina State University 1970; LaFarge and Kraus 1967; Goddard and Strickland 1970). Apparently, a more intensive method of selection is required.

The probability of finding new sources of resistance might be enhanced by selecting in heavily damaged stands. As such areas usually contain few phenotypes desirable in terms of other traits, the advantages of this approach have not been examined thoroughly. It was attempted with some success in a severely infected stand of slash pine in Mississippi, however (Neelands and Jewell 1961). Open-pollinated progenies from a sample of rust-free selections were consistently less susceptible to artificial inoculation than bulk seedlings. This paper reports the results of more comprehensive tests on similar progenies.

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[1] The author is plant geneticist at the Institute of Forest Genetics, Southern Forest Experiment Station, USDA Forest Service, Gulfport, Mississippi.

MATERIALS AND METHODS

While studying the influence of prescribed burning on rust incidence, Dr. P. V. Siggers established a series of four study plots near Laurel, Mississippi. The old field site had been planted with South Georgia-North Florida slash pines at a 6- by 6-foot spacing in 1941. When established in 1946, each plot contained 110 living trees of which 85.4 percent were galled (table 1). Though the incidence of rust varied somewhat from plot to plot, galled trees were uniformly distributed within plots.

Table 1.--Severity of fusiform rust infection on four slash pine selection plots

			1946		1954		
Plot	Area	Trees	Galls[1] per tree	Proportion[2] galled	Galls per tree	Proportion[3] rust-killed	Proportion galled
	Acre	Number	Number	Percent	Number	Percent	Percent
TI-2C	0.158	110	4.4	91.8	7.1	47.3	96.4
TH-3	.153	110	3.6	78.2	7.1	24.3	92.5
TH-4	.167	110	4.6	87.3	4.8	28.4	94.5
TH-3,4C	.175	110	3.9	84.5	5.1	44.0	94.5
Mean	.163	---	4.1	85.4	6.0	36.1	94.5

[1] Galls per living tree detected by observation from the ground.

[2] Living galled trees and rust-killed trees ÷ original trees less those killed by causes other than rust.

[3] Trees rust-killed ÷ original trees less those killed by causes other than rust.

The percentage of trees galled in 1946 probably underestimates the actual incidence of rust. Some galled trees no doubt died and disappeared from the plots and a few may have shed branch galls before the first observation. It seems unlikely, however, that the latter would have remained rust-free. Records taken either annually or biennially from 1946 through 1954 show that both the number of galled trees and the number of galls per tree steadily increased (table 1). Of the trees living in 1954, 91.4 percent were galled. Expressed on a cumulative basis, 94.5 percent of the trees present in 1946 were considered susceptible.

Rust-free phenotypes were selected in 1954. Trees not preserved for study, including several of the least attractive rust-free selections, were removed to provide growing space. The 29 selections currently available include: 16 trees known to have remained rust-free since 1946; 1 rust-free check chosen only on the basis of its appearance in 1954; and 12 rust-infected trees.

Sufficient open-pollinated seed from 12 rust-free selections, five rust-infected selections, and the rust-free check were available for testing in 1968. Included for comparison were open-pollinated seedlings from a resistant standard, 8-7; a susceptible standard, 18-40; and a bulk lot representative of seedlings currently used for reforestation on Mississippi National Forests. Performance of open-pollinated progenies from the resistant and susceptible standards has been verified in the field and under artificial conditions (Dinus 1969). Thirty-day-old seedlings of uniform size were exposed to the pathogen for 72 hours via the artificial inoculation technique developed by Jewell (1960). Row plots of nine seedlings per family were randomly assigned to nursery flats arranged in a randomized block design. All families were represented in at least three replications, but some in as many as seven. After inoculation, seedlings were transplanted to nursery beds in the same design.

Three hundred days after inoculation, the seedlings were lifted and the number having at least one gall was determined for each family. Mortality averaged only 4.6 percent and was uniformly distributed among blocks and families. Variation among families in terms of the proportion of galled seedlings was evaluated with the Chi Square test for independence in r X 2 tables (Steel and Torrie 1960, pp. 370-371). Variation among the several groups of selections was similarly evaluated. Individual Chi Square tests were used to compare the ratios of galled to rust-free seedlings in specific families to those observed in the standard and bulk lots. Differences resulting in Chi Square values larger than that at the 0.05 level of probability were considered significant.

RESULTS

Extensive variation in resistance to fusiform rust was found among families. The incidence of rust averaged 76.6 percent and ranged from a low of 43.5 percent for progeny from a rust-free parent to a high of 91.7 percent for the bulk lot (table 2). Considered as a group, offspring from rust-free parents were less frequently galled than those from rust-infected parents and those from the bulk lot (72.4 versus 86.0 and 91.7 percent, respectively). Progenies from rust-infected parents were also less diseased, on the average, than bulk seedlings. Individual Chi Square tests indicated, however, that the latter difference was largely due to the performance of offspring from one rust-infected selection (J-1-2). The proportion of galled seedlings observed among offspring of this selection was 12.9 percentage points less than the average for its group and approximated that for progenies from rust-free parents. Hence, only one of the five rust-infected selections transmitted any appreciable degree of resistance to its progeny.

Table 2.--Proportions of galled seedlings in open-pollinated slash pine progenies from rust-free selections, rust-infected selections, and four check lots.

Parents: Phenotype and code		Progeny Performance Alive	Galled	Galled
		Number	Number	Percent
Rust-free:	J-1-3	23	10	43.5
	J-1-4	37	23	62.2
	W-1-20	53	33	62.3
Total, best three rust-free:		113	66	58.4
	W-1-22	60	41	68.3
	W-1-6	60	42	70.0
	W-1-25	63	46	73.0
	W-1-14	71	52	73.2
	W-1-3	44	33	75.0
	W-1-2	52	39	75.0
	W-1-7	45	36	80.0
	W-1-5	65	53	81.5
	W-1-19	62	52	83.9
Total, all rust-free:		635	440	72.4
Rust-infected:	J-1-2	26	19	73.1
	W-1-24	69	59	85.5
	W-1-4	35	30	85.7
	W-1-21	37	33	89.2
	W-1-17	61	55	90.2
Total, rust-infected:		228	196	86.0
Checks:				
Rust-free	W-1-8[1]	71	62	87.3
Susceptible	18-40	43	36	83.7
Resistant	8-7	70	39	55.7
Bulk		60	55	91.7
Totals		1107	848	76.6

[1] Data for W-1-8 were excluded from gain calculations as it was chosen only on the basis of its appearance in 1954.

Individual Chi Square analyses indicated that fewer seedlings from every family of rust-free parents were galled than from the bulk lot. If the performance of the bulk seedlings estimates the level of resistance in Mississippi slash pines, the degree of improvement resulting from phenotypic selection under the conditions described equals the difference between the mean for offspring from rust-free parents and that for bulk seedlings. In terms of the proportion galled, the reduction amounts to 19.3 percentage points. Stated as a proportion of the bulk mean, the improvement is 21.0 percent.

Had selection been based only on appearance in 1954, two more of the trees tested would have been considered rust-free. The inclusion of these (W-1-8 and W-1-24) as rust-free parents increased the mean proportion of galled seedlings for this group from 72.4 to 75.0 percent. Offspring from these two parents were as frequently galled as those from the susceptible standard and most of the rust-infected parents (table 2). Nevertheless, the absence of early records would not have greatly decreased the effectiveness of phenotypic selections in this 91.4-percent-galled stand.

Variation in resistance among progenies of rust-free parents was also significant. Since some of this variability is presumably heritable, a further reduction in the average incidence of rust can be expected from selection on the basis of progeny testing. Each of the families from rust-free parents had fewer galled seedlings than the bulk lot. Also, more than half of these families (the best seven) had less rust than offspring of the susceptible standard. Hence, selection on the basis of comparison to the bulk lot or the susceptible standard seemed inefficient. Rather than setting an arbitrary limit in terms of percent galled or, simply, a certain number of parents, the performance of each family was compared to that of the progeny from the resistant standard. Families judged to have an incidence of rust greater than the latter on the basis of individual Chi Square tests were not considered further. Three of the rust-free parents (25 percent) produced progenies which did not differ from the resistant standard. The average proportion of galled seedlings in families from these selections (J-1-3, J-1-4, and W-1-20) was 58.4 percent, 14.0 percentage points less than the mean for all families from rust-free parents (table 2). This reduction is only slightly less than that resulting from phenotypic selection (19.3 percentage points). The total reduction obtained from phenotypic selection combined with elimination on the basis of progeny testing then amounts to 33.3 percentage points. Stated as a percent of the bulk mean, the improvement is 36.3 percent.

DISCUSSION

The open-pollinated progenies of rust-free parents tested in this study were more resistant to artificial inoculation than those from rust-infected parents and, most important, than seedlings representative of the general population. These results agree in general with those from previous studies in which both slash and loblolly pines were tested under artificial (Jewell and Mallett 1967; Kinloch and Kelman 1965) or field conditions (Dinus 1969; Kinloch and Stonecypher 1969). Most previous studies have shown, however, that progenies from rust-free selections are usually, but not always, more resistant than the other types. Hence, selection of rust-free parents has been said to result in moderate gain, and culling based on subsequent progeny tests is considered essential for maximizing gain (Blair 1970). A similar conclusion can be drawn from the present data. Phenotypic selection resulted in progeny with an average incidence of rust 19.3 percentage points less than that in bulk seedlings. Had three-fourths of the rust-free parents been culled on the basis of progeny testing, the amount of rust in progenies from the remaining parents would have been reduced by an additional 14.0 percentage points.

The improvement resulting from phenotypic selection is especially encouraging in that these were open-pollinated progenies tested under conditions designed to enhance the probability of infection. Most pollen can be assumed to have come from the surrounding, large area of unselected trees. Even so, each family was less susceptible than seedlings typical of those currently used for reforestation in Mississippi. These results suggest that phenotypic selection can be a reliable method for locating new sources of resistance.

For phenotypic selection to be effective, critical attention must be given to stand and individual-tree characteristics. For example, only marginal differences in resistance to artificial inoculation were found among progenies of rust-free and rust-infected loblolly pines (Kinloch and Kelman 1965). The parents were from a 35-year-old stand in which only 62 percent of the trees were galled. In another study, the proportion of galled seedlings in progenies from controlled matings among rust-free parents varied from 9 to 99 percent (Jewell and Mallett 1967). These trees were from a 75-percent-galled stand of slash pine. In neither case were individual tree histories known. Under such circumstances, the phenotype cannot be expected to and did not provide a reliable estimate of the genotype.

Rust incidence averaged 91.4 percent when the present selections were chosen. Individual tree records, available except for the first 5 years, indicated that 94.5 percent of the trees were galled at one time or another. Even under these circumstances, considerable variation was found among progenies. Only 25 percent of the rust-free parents produced offspring as resistant as those from the best standard. Should a similar proportion of the untested selections prove as acceptable, a total of four outstanding selections will have been found. This total represents only 0.9 percent of the trees present in 1946 and approximately 0.5 percent of those originally planted. Of the rust-free parents tested, however, all produced progenies less susceptible than bulk seedlings. All 16 selections available could therefore be useful. Ignoring the several that died before or after selection, these comprise 3.6 percent of the trees present in 1946 or about 2.0 percent of the original stand. Hence, trees that have escaped exposure, that have undetectable galls, or that have shed branch galls via natural pruning will be quite frequent where rust is less severe.

Phenotypic selection then can only be as effective as reported here when rust incidence is as great at the time of selection as in this instance or when records are available on the performance of individual trees during past epidemics. Selection in plantations subjected to more moderate, but uniform exposure over a period of years would probably yield less, but nevertheless substantial, improvement. Existing progeny test plantations in hazardous areas also seem logical places to seek new sources of resistance via phenotypic selection.

LITERATURE CITED

Barber, J. C. 1961. Growth, crown form, and fusiform rust resistance in open-pollinated slash pine progenies. Sixth South. Forest Tree Improv. Conf. Proc. 1961: 97-104.

Barber, J. C. 1966. Variation among half-sib families from three loblolly pine stands in Georgia. Ga. Forest Res. Counc. Ga. Forest Res. Pap. 37, Macon, Ga. 5 pp.

Blair, R. L. 1970. Quantitative inheritance of resistance to fusiform rust in loblolly pine. Ph. D. Diss. N. C. State Univ., Raleigh, N. C.

Davis, T. C., and Goggans, J. 1968. Fusiform rust in southern pines. Auburn Univ. Agric. Exp. Stn. Highlights of Agric. Res. 15(3): 10.

Dinus, R. J. 1969. Testing slash pine for rust resistance in artificial and natural conditions. Tenth South. Forest Tree Improv. Conf. Proc. 1969: 98-105.

Goddard, R. E., and Strickland, R. K. 1970. Cooperative Forest Genetic Research Program, 12th Progress Report. Univ. Fla. Sch. of Forest. Res. Rep. 18, 36 pp.

Jewell, F. F. 1960. Inoculation of slash pine seedlings with Cronartium fusiforme. Phytopathology. 50: 48-51.

Jewell, F. F., and Mallett, S. L. 1967. Testing slash pine for rust resistance. Forest Sci. 13: 413-18.

Kinloch, B. B., and Kelman, A. 1965. Relative susceptibility to fusiform rust of progeny lines from rust-infected and noninfected loblolly pines. Plant Dis. Rep. 49: 872-74.

Kinloch, B. B., and Stonecypher, R. W. 1969. Genetic variation in susceptibility to fusiform rust in seedlings from a wild population of loblolly pine. Phytopathology. 59: 1246-55.

LaFarge, T., and Kraus, J. F. 1967. Fifth-year results of a slash pine polycross progeny test in Georgia. Ninth South. Forest Tree Improv. Conf. Proc. 1967: 86-91.

Neelands, R. W., and Jewell, F. F. 1961. The search for pest-resistant trees. Forest Farmer 21(1): 15, 26, 28.

North Carolina State University. 1970. Cooperative tree improvement and hardwood research programs. 14th Annu. Rep. N. C. State Univ., Raleigh, N. C. 88 pp.

Steel, R. G. D., and Torrie, J. H. 1960. Principles and procedures of statistics. McGraw-Hill Book Co., Inc. 481 pp.

GENETIC VARIATION IN RESISTANCE TO FUSIFORM RUST AMONG SELECTED PARENT CLONES OF LOBLOLLY PINE AND THEIR OFFSPRING

B. B. Kinloch, Jr. and M. H. Zoerb [1]

ABSTRACT

Variation in fusiform rust infection among 10 clones of loblolly pine in an industrial seed orchard in South Carolina ranged from 0-92%. In four progeny tests established in different years and locations, full-sib families from these parents also differed significantly in amount of rust infection and tended to reflect the relative susceptibility of their parental phenotypes. Although the average resistance of progenies from superior phenotypes selected in the wild was no better than that of commercial nursery stock, selection of parents on the basis of their clonal performance in areas of high natural rust hazard would be much more effective.

INTRODUCTION

Fusiform rust, caused by Cronartium fusiforme Hedgc. and Hunt ex Cumm., is a limiting factor to plantation management of loblolly (Pinus taeda L.) and slash (P. elliottii Engelm.) pines in large parts of the southern United States, where environmental conditions favor the development and spread of the disease. Thus, in breeding programs aimed at the genetic improvement of these species, incorporation of resistance is essential. Although extensive genetic variation in resistance has been found in natural populations (Barber 1964, 1966; Kinloch and Stonecypher 1969; Blair 1970), progeny testing has been the only reliable means of evaluating parent selections. Trees superior in growth or other economic traits are usually excluded from clonal breeding orchards if any symptoms of fusiform rust are found, but the efficacy of this selection on improved rust resistance in their progeny is not well known. Rust-free parents generally, but not always, transmitted greater resistance to their offspring than infected trees (Jewell and Mallett 1967; Kinloch and Stonecypher 1969), but accurate phenotypic evaluation of mature trees for rust resistance is difficult at best. The candidate tree is a single unit observed at one point in time, and evidence of previous infection, which most often occurs on branches, is usually lost through natural pruning. Also, candidates are selected from many different stands covering a wide geographic area, where the potential hazard and intensity of the disease varies greatly.

This paper reports information on the variation in susceptibility among individual clones of loblolly pine grown in a common environment of high hazard to fusiform rust, and early results on their parent-offspring relationships.

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[1] Geneticist, Pacific Southwest Forest and Range Experiment Station, Forest Service, U. S. Department of Agriculture, Berkeley, California; and Research Forester, Union Camp Corp., Savannah, Georgia, respectively.

MATERIALS AND METHODS

Parent trees were selected from mature natural stands of loblolly pine in the lower coastal plain of South Carolina and Georgia. Criteria for selection were phenotypic superiority in growth rate and other traits of commercial importance, and absence of fusiform rust symptoms, though in some stands the incidence of the disease was low or lacking. Scions from selected trees were grafted in the Union Camp seed orchard near Almeda, South Carolina, between 1959 and 1962. There were 6-45 ramets/clone, completely randomized within the orchard. Rust infection on pines in the surrounding area was severe: trees in a plantation established in 1958 within 500 ft. of the orchard were 98% infected, with an average of 7.6 galls/tree.

Candidate trees were bred in the orchard to four tester trees, but insufficient flowering and seed set of some resulted in an incomplete mating design. After growing a year in a nursery, four different plantations of controlled-pollinated families were outplanted in 1965, 1966, and 1967 on two different sites within a 50-mile radius of Savannah, Georgia. The experimental design was a randomized complete block with 10 trees/plot in rows. In three of the plantations (main tests) there were six replications, and in the fourth (supplementary test) only three replications. The number of different families in each test varied, but 10 families were common to all tests. Only these 10 families are considered in this report. Open-pollinated seedlings of unknown parentage from a commercial nursery were also included in each test as checks.

Orchard trees were examined for fusiform rust symptoms in 1967, and plantation trees in 1969. In the plantations, the unit of analysis was the percentage of trees infected per plot (transformed to arc sin $\sqrt{\text{percentage}}$ equivalents when variance analyses were made). In the clonal seed orchard, galls were counted on every ramet.

RESULTS AND DISCUSSION

Variation in susceptibility to fusiform rust among the 10 different clones was striking, ranging from 0-92% infection and averaging from 0-5 galls/tree (Table 1). Differences of this magnitude in such a relatively small sample of parents demonstrate the great amount of inherent variation that exists among individual genotypes in natural populations of loblolly pine. Nevertheless, the amount of infection observed on the clones was light in comparison to the 98% infection and average of 7.6 galls/tree found in the nearby plantation, established from seed at approximately the same time. This disparity may be associated with differences in the physiological age of the two groups of trees.

Differences in the amount of rust infection among the 10 families common to four progeny tests were also great. For example, in the 1966 (main) test, families ranged from 12-66% infected; in 1967, they ranged from 3-64% infected (Table 2). This degree of variation is typical of young loblolly pine (Barber 1966; Kinloch and Stonecypher 1969; Blair 1970).

Table 1.--Fusiform rust infection on clones of loblolly pine in a seed orchard

Clone designation	No. of ramets	% infection	Avg. no. galls/ramet
6	45	0.0	0.0
12	37	10.8	0.1
5	32	18.7	0.3
14	41	29.2	0.4
25	22	31.8	0.5
38	49	42.8	0.6
18	54	64.8	1.0
16	12	75.0	1.6
37	6	88.3	1.1
8	25	92.0	5.0

Table 2.--Fusiform rust infection on 10 controlled-pollinated families common to four different progeny tests, and commercial checks of unknown parentage

	Year of planting			
	1965	1966	1967 (MT)[a]	1967 (ST)[a]
	- - - - - - - - - - % Infection - - - - - - - - - -			
Avg. of 10 selects	17	43	38	16
Range among selects	5-38	12-66	3-64	7-29
Commercial checks	25	38	21	8

[a] MT = Main Test
ST = Supplementary Test

Of equal importance was the consistent performance of the families from test to test. Although the total amount of infection among the four tests varied considerably (Table 1), families tended to maintain their relative rankings in degree of susceptibility over all the tests (Table 3). The few important exceptions to this trend all occurred in the plantation with the least amount of infection (1967, supplementary test) and, therefore, probably containing the least reliable data.

Although relatively few parents were common to all tests, parent-offspring relationships were demonstrated quite clearly. The average rank in rust resistance in four tests for each of the 10 families agreed closely with the rank predicted on the basis of the mid-parent values of their parental clones (Table 3).

Table 3.--Relative rankings in resistance to fusiform rust infection of 10 controlled-pollinated families of loblolly pine common to four progeny tests

Cross	Rank[a] in test year: 1965	1966	1967 (MT)[b]	1967 (ST)[b]	Avg. rank	Expected rank[c]
5 x 25	1	1	1	3	1	1
25 x 14	4	3	2.5	1	2	2
37 x 6	3	2	2.5	6	3	3
37 x 14	5	7	5	2	4.5	7
18 x 25	2	4	4	9	4.5	4
5 x 8	7	5.5	6	5	6.5	6
16 x 37	6	5.5	8	4	6.5	9
12 x 8	9	8	9	7	8	5
14 x 8	10	9	7	8	9	8
16 x 8	8	10	10	10	10	10

[a] Based on percentage of trees infected.
[b] MT = Main Test; ST = Supplementary Test.
[c] Based on mid-parent values, computed from Table 1.

These data show that the original selection of parents in the wild was not effective in improving rust resistance in their offspring since unselected stock from a commercial nursery was less susceptible in most cases (Table 2). However, parents were selected over a wide geographic range, and in some areas where the intensity of rust was low, phenotypes for resistance could not be accurately evaluated. Selection on the basis of clonal performance in an area of high natural rust hazard, on the other hand, appears to be a much more effective alternative. This is proposed as a potentially valuable complement to progeny testing.

LITERATURE CITED

Barber, J. C. 1964. Inherent variation among slash pine progenies at the Ida Cason Calloway Foundation. U.S. Forest Serv., Southeast. Forest Exp. Sta. Res. Pap. SE-10, Asheville, N. C. 90 pp.

Barber, J. C. 1966. Variation among half-sib families from three loblolly pine stands in Georgia. Georgia Forest Res. Counc. Pap. 37, Macon. 5 pp.

Blair, R. L. 1970. Quantitative inheritance of resistance to fusiform rust in loblolly pine. Ph.D. Thesis, Dep. Forest Management, N. C. State Univ., Raleigh. 87 pp.

Jewell, F. F., and Mallett, S. L. 1967. Testing slash pine for rust resistance. Forest Sci. 13: 413-418.

Kinloch, B. B., Jr., and Stonecypher, R. W. 1969. Genetic variation in susceptibility to fusiform rust in seedlings from a wild population of loblolly pine. Phytopath. 59: 1246-1255.

INOCULATION OF LOBLOLLY PINES WITH CRONARTIUM FUSIFORME AT DIFFERENT LEVELS OF INTENSITY

H. R. Powers, Jr., H. J. Duncan, L. D. Dwinell, and Thomas Miller [1]

Many research groups in the South are selecting and testing loblolly (*Pinus taeda* L.) and slash (*P. elliottii* var. *elliottii*) pines for possible resistance to fusiform rust caused by *Cronartium fusiforme* Hedgc. & Hunt ex Cumm. Parent trees are usually selected on the basis of several growth and yield traits and freedom from rust infections. To reduce the probability of selecting a tree that has escaped infection, research scientists try to make evaluations in areas where the incidence of disease is very high. We prefer areas where more than 85 percent of the trees are infected.

Once parent trees have been chosen, evaluations of resistance have usually been based on the field performance of either open- or control-pollinated progeny from specific parent trees. Field tests are effective but require at least 3 or 4 years for completion. Furthermore, there is no guarantee that the seedlings will be subjected to infection by the rust in any given area. Heavy rust infections usually occur in nature only once every 4 or 5 years in a given location. During the last 5 years in Greene County, Georgia, only 1966 could have been considered a severe rust year. A progeny test in that year would have given seedlings a vigorous natural screening. Since that time, rust infections have been light to moderate. This means that seedlings planted in the winter of 1966-67, after 4 years in the field, would have been thus far inadequately tested at this location. If rust infections are light during the 1971 and 1972 seasons, these seedlings would miss being tested during the most advantageous period for evaluation.

Because of the difficulties involved in field testing for resistance, plant pathologists have worked for many years to develop a reliable means of artificially inoculating seedlings. Most of the techniques tried have involved suspending oak leaves bearing telial columns above the pine seedlings to be inoculated (Jewell 1960). The high humidity and approximately 70°F. temperature required for heavy infections have usually been maintained in a canvas tent or a combination of tent and shed. Refrigerated moist chambers of various types have also been used to achieve the same results when temperatures are too high. Variations on this basic principal have been developed (Dwinell, in press; Snow and Kais, in press) which give much more accurate control of humidity, temperature, and levels of infection, but facilities are limited in size.

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[1] Senior Plant Pathologist, Forestry Research Technician, and Research Plant Pathologists, USDA Forest Service, Southeastern Forest Experiment Station, Forestry Sciences Laboratory, Athens, Georgia 30601.

Other specialized inoculation techniques, which may vary considerably from normal conditions, have been developed for specific research purposes. In one of these, telial columns are inserted directly into a cut on stems of seedlings (Hedgcock and Siggers 1949). Other techniques use basidiospores that have been cast from telia suspended over water. The spores are then injected into seedlings with a hypodermic needle (Powers 1968), or placed at specific points on the seedling with a fine glass rod (Miller 1970). All of these techniques depart to varying degrees from the normal means of infection, but do permit infection of specific tissues at precise points. These procedures, while achieving definite research objectives, probably would not be satisfactory for evaluating seedling resistance or susceptibility on a large scale.

A key element lacking in all of this work is host material which will give a relatively uniform disease response to specific levels or concentrations of inoculum. Host material of this type would make it possible to simplify the evaluation of the various techniques.

Another serious problem facing researchers, particularly those who make large scale inoculation tests in tents or moist chambers, has been the erratic germination of telia, resulting in uneven patterns of infection. This has been less of a problem when fresh field-collected material was used as inoculum than in cases where year-round inoculations are attempted with inoculum produced under greenhouse conditions. Usually, telia produced in the greenhouse are satisfactory, but occasionally germination is poor. The newer, more carefully controlled inoculation procedures of Dwinell and Snow eliminate some of these difficulties.

It is obvious that several choices of inoculation techniques are possible when evaluating rust resistance of seedlings. During 1969, studies were designed to test open-pollinated progeny from several parent tree selections and also to evaluate the capacity of three inoculation procedures to provide a range of inoculum densities. These tests were designed to provide information on the overall resistance or susceptibility of the selections, to find the range of inoculum levels obtainable with different techniques, and to determine if any possible resistance would hold constant over a wide range of inoculum densities.

METHODS

Three different inoculation procedures were used. The most severe tests were made with the first method, in which seedlings were inoculated in a large temperature-controlled moist chamber at 70°F. Inoculum density was not recorded for each test in this chamber, but a Kramer-Collins spore sampler (Kramer and Pady 1966) used during one run gave a count of over one million basidiospores per cubic foot of air sampled. In this case, northern red oak leaves bearing telia were suspended 2 to 3 inches above the test seedlings. The second inoculation technique was that described by Miller and used precast basidiospores. This technique involved the deposition of inoculum directly onto the growing tip of the test seedlings by means of a glass rod. The third method involved the use of an inoculation chamber with closely controlled humidity and temperature (Dwinell, in press). This apparatus makes it possible to vary the inoculum density by adjusting the number of telia exposed over each of several streams of moist air entering the chamber. This method provided moderate to light inoculum densities--150,000 to 17,000 spores per cubic foot of air sampled.

The plant material used was open-pollinated progeny from three loblolly pine parent tree selections. Selection 29R was a rust-free tree from a progeny test in Houston County, Georgia. This was an area of high rust incidence. A total of 915 seedlings were available for testing from this parent tree. Selection 30R was an apparently rust-free tree from an area of moderate rust incidence near Athens, Georgia. One rust gall was subsequently found on this selection. Over 700 seedlings from this source were inoculated. The third parent tree, Number 4628-02, was selected from the same area as 29R for use as a highly susceptible check. Only 178 seedlings were available from this selection, and they were only inoculated in the large moist chamber to give an overall basis for comparison. The 29R and 30R seedlings were tested with all the inoculation procedures listed.

Because of the large number of seedlings being tested in our program, we carry out inoculation tests almost constantly in the large moist chamber. The sometimes erratic germination of telia makes it necessary to split seed lots to avoid the possibility of one entire group being tested with a low level of inoculum. The groups of seedlings discussed in this report were tested in the large chamber on 5 different inoculation runs. Seedlings inoculated by Miller's procedure were all done on the same day, and the seedlings inoculated in Dwinell's chamber were done on three different days. In this latter case, the inoculum densities for the three runs were 150,000, 107,000 and 17,000 spores per cubic foot of sampled air, respectively.

RESULTS

Infection of seedlings exposed to the heaviest inoculum densities in the large moist chamber ranged from 100 percent in the case of 4628-02, the most susceptible, to 45 percent with 29R, the most resistant (Table 1). In this test, as well as all others, 30R seedlings were intermediate with 72 percent infection. When the results from all five runs in the large moist chamber were averaged, the incidence of rust was lower, ranging from 81 percent for 4628-02 to 36 percent for 29R. With Miller's less severe technique, the infection levels were 44 percent and 21 percent for 30R and 29R, respectively.

The three different inoculation levels in Dwinell's chamber gave increasingly lower infections with decreasing inoculum densities. There were insufficient seed of 30R for a satisfactory test at the lightest inoculation level, which gave 2 percent infection on 29R.

Table 1.--Results of inoculations of progeny from loblolly pine selections with basidiospores of *Cronartium fusiforme* using different procedures and at different levels of intensity.

Type of inoculation	Seedlings infected [1/]		
	29R	30R	4628-02
	Percent	Percent	Percent
Heaviest inoculation-moist chamber [2/]	45	72	100
Average of 5 runs-moist chamber	36	63	81
Point inoculation with glass rod	21	44	-
Inoculation with controlled inoculum densities:			
150,000 spores/ft^3	11	27	-
107,000 "	5	17	-
17,000 "	2	-	-

[1/] Infection percentages determined by gall development on infected seedlings.

[2/] Spore samples from one heavy inoculation run indicated over one million spores per cubic foot of air sampled.

DISCUSSION

The three most important results of this study were the constant resistance of 29R, the correlation between inoculum density and subsequent gall development, and the production of infection rates fairly close to the level desired. Seedlings from selection 20R were consistently more resistant than 30R throughout the tests. The susceptible check was more susceptible than 30R in the two comparisons that were possible. This means that carefully controlled inoculation tests can produce infection levels ranging from extremely heavy to very light, depending upon the inoculum density. The ability to produce specified infection rates and the development of pine host material that gives a relatively constant infection response means that seedlings can be evaluated for rust resistance much more effectively.

In addition, the results of this study indicate that even in the case of selections which eventually prove to be galled in the field, there may be some gain in the level of resistance compared to a susceptible check. Selection 4628-02, which had several rust galls and might represent a poor commercial lot, had from 18 to 28 percent more rust than 30R under relatively heavy infection conditions.

LITERATURE CITED

Dwinell, L. D. An inoculation system for *Cronartium fusiforme*. *In* NATO-IUFRO Advanced Study Institute on "Basic Biology and International Aspects of Rust Resistance in Forest Trees." (In press)

Hedgcock, George G., and Paul V. Siggers. 1949. A comparison of the Pine-Oak Rusts. U.S.D.A. Tech. Bull. 978, 30 pp.

Jewell, F. F. 1960. Inoculation of slash pine seedlings with Cronartium fusiforme. Phytopathology 50: 48-51.

Kramer, C. L., and S. M. Pady. 1966. A new 24-hour spore sampler. Phytopathology 56: 517-520.

Miller, Thomas. 1970. Inoculation of slash pine seedlings with stored basidiospores of Cronartium fusiforme. Phytopathology 60: 1773-1774.

Powers, H. R., Jr. 1968. Distance of needle infection from stem affects likelihood of gall development on slash pine by Cronartium fusiforme. Phytopathology 58: 1147-1149.

Snow, G. A. and A. G. Kais. Technique for inoculating pine seedlings with *Cronartium fusiforme*. *In* NATO-IUFRO Advanced Study Institute on "Basic Biology and International Aspects of Rust Resistance in Forest Trees." (In press)

EVALUATION OF THE 24-YEAR OLD TABLE ROCK (S. CAROLINA) CHESTNUT PLOT FOR GROWTH AND DISEASE RESISTANCE AND A PROPOSED BREEDING PROGRAM FOR ITS USE

C. R. Nichols, R. E. Schoenike, and Wesley Witcher[1]

The American chestnut (Castanea dentata (Marsh.) Borkh.) has been almost completely killed throughout its native range in the United States by the chestnut blight fungus (Endothia parasitica (Murr.) A. & A.). Beginning in 1925, several state, private, and government agencies have been involved in breeding attempts to find a chestnut tree that is resistant to the fungus. The story has been reported elsewhere (Beattie and Diller, 1954; Diller and Clapper, 1965; Diller and Clapper, 1969; King, 1970) and will not be repeated here.

Beginning in 1947, a series of plots was established under the leadership of Dr. Jesse D. Diller of the Division of Plant Pathology, U. S. Dept. Agriculture. During the period, 1947-1955, 15 plots were established in 13 states throughout most of the range of the American chestnut. Southern states included in the test plantings were Arkansas, Alabama, Tennessee and South Carolina. The plots consisted of chestnut hybrids of various pedigrees and some of the Chinese chestnut (Castanea mollissima Bl.). A recent evaluation of the 15 plots was made by Diller and Clapper (1969).

THE TABLE ROCK PLOT

The South Carolina State Commission of Forestry cooperated in this study by establishing a one-half acre plot in April 1948 at Table Rock State Park in upper Pickens County, South Carolina. The plot lies at 1100 feet elevation and is considered above average for hardwoods in the area, having fertile and well-drained soil. The site has a low southwest exposure and before planting supported a mixed stand of yellow poplar, sweetgum, red maple, red oak, white ash, and dogwood. The dominant yellow poplar averaged 4-6 inches dbh. After planting all trees and shrubs over three feet in height were cut or girdled.

The 1-0 seedlings obtained for planting were grown by the U. S. Dept. of Agriculture at Glenn, Dale, Maryland, and by the Connecticut Agr. Expt. Station at Hamden, Connecticut. A total of 125 seedlings were planted at an approximate spacing of 10 x 10 feet on April 12, 1948. Of the seedlings planted, 68 were hybrids developed by Arthur H. Graves at Hamden. The Glenn Dale trees were developed by Russell B. Clapper and consisted of 19 hybrids, 16 Chinese chestnut (Nanking strain), P. I. 58602, and 19 open-pollinated American X Chinese chestnut hybrids. Three trees could not be identified with certainty because one of their two tags was missing. The other set of tags had numbers that indicated they were Connecticut hybrids and are so treated here. The planting site was an irregular area fitted into a mountain cove. Eight rows consisting of 5 to 26 seedlings per row made up the plot. The seedlings were assigned to the space in a pre-arranged randomized manner.

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[1] Respectively, Forest Management Assistant, South Carolina Commission of Forestry, Columbia, S. C.; Associate Professor, Department of Forestry, Clemson University, Clemson, S. C.; and Professor, Department of Plant Pathology and Physiology, Clemson University, Clemson, S. C.

Since planting the plot has been maintained by periodically girdling edge trees and removing sprouts and understory vegetation competing with the chestnut trees. The plot is in good condition at the present time.

COLLECTION OF DATA

On January 29, 1971, the authors made a detailed survey of the plot. Data were obtained on survival, diameter, height, blight resistance, and tree form of all chestnut trees on the plot. Diameters were measured with diameter tape and recorded to the nearest 0.1 inch. Heights were obtained with a Haga and recorded to the nearest foot. Blight resistance was assessed as noted by large number of cankers and dieback. Tree form from a timber type point of view was also gauged in five categories ranging from excellent to valueless.

ANALYSIS OF RESULTS

1. Survival (Table 1)

First year survival was 77 percent. Losses since 1949 have further reduced the number of surviving trees to 71 (57 percent) as of January 1971. The age of the trees at that time was 24 years. Earlier losses can be attributed to damage in planting, and competition from edge trees and sprouts. Animal damage was minimal. The onset of blight on the plot was not noted in the old records but it was obvious that some trees had succumbed to the disease. The Chinese chestnuts and open-pollinated hybrids survived somewhat better than the controlled hybrid crosses.

Table 1. Number Planted and Survival of Four Groups of Chestnut Trees at Table Rock State Park, S. C. (Age - 24 yrs.)

Group	Number Planted	Number Surviving	Percent Surviving
Chinese-Nanking 58602	16	11	69
American-Chinese OP	19	13	68
Maryland Hybrids	19	11	58
Connecticut Hybrids	71*	36	50
	125	71	57

* Including 3 trees whose identity is not certain but most likely belonged to this group. See text.

2. Size of trees (Tables 2 and 3)

The data are grouped into ten, one-inch diameter classes and six, ten-foot height classes. Means were computed from a weighted value depending on the number of trees in each class. As a group the American-Chinese OP hybrids were clearly superior to the others in both diameter and height.

Table 2. Number of Trees by One-inch Diameter (DBH) Classes for Four Groups of Chestnut Trees at Table Rock State Park, S. C. (Age - 24 yrs.)

	Inch - Diameter Classes											
Group	1	2	3	4	5	6	7	8	9	10	Totals	Means
Chinese-Nanking 58602	2	0	1	2	2	2	1	0	1	0	11	4.6
American-Chinese OP	0	1	2	0	1	3	3	1	2	0	13	6.0
Maryland Hybrids	2	1	0	3	2	0	1	1	0	1	11	4.6
Connecticut Hybrids	4	3	1	7	8	8	3	1	0	1	36	4.7
Totals	8	5	4	12	13	13	8	3	3	2	71	4.9

Table 3. Number of Trees by Ten-foot Height Classes for Four Groups of Chestnut Trees at Table Rock State Park, S. C. (Age - 24 yrs.)

	Ten-foot Height Classes							
Group	0-9	10-19	20-29	30-39	40-49	50-59	Totals	Means
Chinese-Nanking 58602	0	2	2	4	2	1	11	33
American-Chinese OP	0	1	1	3	6	2	13	40
Maryland Hybrids	1	2	1	4	1	2	11	32
Connecticut Hybrids	1	3	6	16	8	2	36	34
Totals	2	8	10	27	17	7	71	35

3. Blight-resistance (Table 4)

The categories were determined on the basis of evidence of blight. Such evidence consisted in number of cankers present, presence of sprouts where the main stem had died, and dieback of tops. The categories, though not as precise as the numerical data obtained from tree size, are believed to be reasonable ones. It was seldom difficult to place a tree in one of the five categories. A surprisingly large number of trees (40 %) were placed in the blight-free category. The American-Chinese OP hybrids and Connecticut hybrids showed slight superiority in blight resistance to the other groups.

Table 4. Number of Trees by Blight-resistance Categories for Four Groups of Chestnut Trees at Table Rock State Park, S. C. (Age - 24 yrs.)

	Blight-resistance Categories						
	5	4	3	2	1		
Group	None	Light	Moderate	Heavy	Severe	Totals	Means
Chinese-Nanking 58602	4	0	3	4	0	11	3.4
American-Chinese OP	5	6	0	1	1	13	4.0
Maryland Hybrids	3	2	2	2	2	11	3.2
Connecticut Hybrids	17	7	6	2	4	36	3.9
Totals	29	15	11	9	7	71	3.7

4. Tree Form (Table 5)

From a timber tree point of view, the trees were rated in five categories ranging from excellent to valueless. Means were again determined by giving the categories numerical values. The table shows that the American-Chinese OP trees were superior to those of other groups.

Table 5. Number of Trees by Tree Form Categories for Four Groups of Chestnut Trees at Table Rock State Park, S. C. (Age - 24 yrs.)

Group	Tree Form Categories 5 Excellent	4 Good	3 Average	2 Poor	1 Valueless	Totals	Means
Chinese-Nanking 58602	0	1	3	6	1	11	2.4
American-Chinese OP	1	4	6	1	1	13	3.2
Maryland Hybrids	1	2	2	5	1	11	2.7
Connecticut Hybrids	1	7	15	10	3	36	2.8
Totals	3	14	26	22	6	71	2.8

5. Summary of Results (Table 6)

In four of five categories, the open-pollinated American-Chinese hybrids were superior to the other chestnuts. This superiority might be attributed to the following: (1) There appears to be a higher percentage of American chestnut genes in these trees than in most of the others. In the Glenn Dale hybirds, Clapper used many Chinese-American hybrids backcrossed to Chinese chestnut; and in the Connecticut hybrids, Graves also used the Japanese chestnut (Castanea crenata Sieb. & Zucc.) extensively (see Diller, Clapper, and Jaynes, 1964 for a partial pedigree list of these hybrids). This species is a smaller tree than the Chinese chestnut and generally less vigorous when grown in this country (Wyman, 1965). (2) The proportion of inbreeding may have been higher in the Glenn Dale and Hamden hybrids due to heavy use of a few selected trees. The pedigrees of many hybrids are not known.

Table 6. Summary Values for Four Groups of Chestnut Trees at Table Rock State Park, S. C. (Age - 24 yrs.)

Group	Rankings Survival	Diameter	Height	Blight	Form	Sum of Ranks	Final Ranks
Chinese-Nanking 58602	1	3	3	3	4	14	3
American-Chinese OP	2	1	1	1	1	6	1
Maryland Hybrids	3	3	4	4	3	17	4
Connecticut Hybrids	4	2	2	2	2	12	2

A PROPOSED BREEDING PROGRAM

1. Selection

In selecting trees for a breeding program from this plot, all categories of species and hybrids will be considered. On a combination of growth, form, and disease resistance patterns, three of the 71 trees were rated superior to all others. These are:

- F-28, an American-Chinese OP, 6.9 in. dbh, 51 ft. tall, excellent form, blight-free;
- F-31, a Glenn Dale Hybrid, 10.0 in. dbh, 58 ft. tall, excellent form, blight-free - this is the tallest tree on the plot;
- F-65, a Hamden Hybrid, 7.6 in. dbh, 44 ft. tall, good form but with some heavy limbs, blight-free;

Several others including F-67 (a Hamden hybrid, 11.2 in. dbh (largest), 56 ft. tall, form fair but with heavy limbs, blight-free, best seed producer in 1969 and 1970) could be rated very good and may be acceptable in a breeding program.

In their 1964 evaluation, Diller, Clapper, and Jaynes recommended that vigorous trees averaging two feet or more of height growth per year should be evaluated for their forestry potential. On this basis ten trees of the 71 present (14 percent) would be considered. However, form and disease factors reduce this number so that the number of fully acceptable trees is much fewer. For example, Tree F-26 is 9.7 in. dbh and 54 ft. tall, but it displays many cankers despite its present vigor, and would not be acceptable in a breeding program.

2. Propagation

Vegetative propagation, including grafting and the rooting of cuttings, and seed propagation will both be attempted for the better trees. Grafting of chestnut scions unto suitable rootstock is a well-known technique and has been practiced for many years (Jaynes and Graves, 1963). Rooting of cuttings has not given consistent results although certain clones may root quite well. Seed propagation is easiest and may well be the best method. Mass planting of O-P seed from the better trees would assure a broad genetic base and allow a greater choice for selecting superior trees. Crossing desirable clones, such as those listed above, will also be attempted.

The development of superior, disease-resistant chestnut trees for forestry purposes is still a task for the future. From plantings, such as those at Table Rock and others established over the past 25-30 years, tree breeders have hopes of bringing the chestnut back. That hope seems brighter now than ever before.

LITERATURE CITED

Beattie, R. K. and J. D. Diller. 1964. Fifty Years of Chestnut Blight in America. J. Forestry 52:323-329.

Diller, J. D., R. B. Clapper, and R. A. Jaynes. 1964. Cooperative test plots produce some promising Chinese and hybrid chestnut trees. U. S. Forest Serv. Res. Note NE-25. 7 pp.

Diller, J. D. and R. B. Clapper. 1965. A progress report on attempts to bring back the chestnut tree in eastern United States. 1954-1965. J. Forestry 63:186-188.

Diller, J. D. and R. B. Clapper. 1969. Asiatic and hybrid chestnut trees in the eastern United States. J. Forestry 67:328-331.

Jaynes, R. A. and A. H. Graves. 1963. Connecticut Hybrid Chestnuts and Their Culture. Conn. Agr. Expt. Sta. Bull. 657. 29 pp.

King, Barrington. 1970. Will the Chestnut Return? Sandlapper Magazine 4(8):50-51, 77-79.

Wyman, Donald. 1965. Trees for American Gardens, Rev. Ed., p. 179. The MacMillan Co., New York, N. Y.

VARIABLE SUSCEPTIBILITY TO *Dioryctria* *amatella* (HULST) (Lepidoptera: Phycitidae) AMONG PINES IN CLONAL SEED ORCHARDS

C. F. Sartor and W. W. Neel[1]

Concern over seed losses due to cone insect damage in pine seed orchards is increasing annually. The coneworm, *Dioryctria amatella* (Hulst) (Lepidoptera: Phycitidae), is one of the primary pests of pine cones in the southeastern United States. A recent study by Sartor and Neel (1971) has shown that the coneworm does cause significant losses in seed yields in 2 Mississippi pine seed orchards.

Clonal seed orchards offer an excellent opportunity to screen phenotypes for possible sources of host plant resistance to insect infestation. Merkel et al. (1965) provided data that suggest there are inherent differences among slash pines in resistance to *Dioryctria* attack of cones and stems.

This study was intended as a preliminary step in screening genetic clones of slash and loblolly pines for inherent differences in coneworm infestation rates.

METHODS

Three clonal pine seed orchards in Mississippi were available for study; the McNair Orchard (International Paper Company)in Jefferson County, the Erambert Orchard (United States Forest Service) in Perry County, and the Scott Paper Company Orchard in Greene County.

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[1] Graduate Research Assistant and Associate Professor, respectively, Department of Entomology, Mississippi State University.

Entire 2nd-year cone crops were collected from sample trees in each orchard during the harvest seasons. Loblolly cones were collected by hand and slash cones were collected by hand and with a tree shaker. Coneworm infestation rates were recorded for individual trees.

In the 2 loblolly orchards studied (McNair and Erambert Orchards), only those clones with 5 or more trees with adequate 2nd-year cone crops (10 or more cones/tree) were used as sample units. Every clone in the slash orchard that had 2 or more trees with adequate cone crops were used. Not all clones in any of the orchards met these specifications, and not all the genetic sources were sampled. Selection of sample trees within each clone was not made by a completely random method and unequal numbers of sample trees per clone were used so that as many clones as possible could be screened.

RESULTS

Rates at which the coneworm infested cones in pine seed orchards were recorded for 1969 and 1970 (Table 1). These data show that 2nd-year slash cones were more heavily infested than 2nd-year loblolly cones. However, no insecticides had been applied in the Scott Paper Company orchard or in the Erambert Orchard. These 2 orchards had the highest infestation rates which could be considered as indicative of coneworm control in the McNair Orchard where insecticides had been applied. Data in Table 1 also show there was considerable variation between the 1969 and 1970 infestation rates within 2 of the orchards.

Table 1.--Infestation rates of 2nd-year loblolly and slash cones by D. amatella at harvest time in 3 pine seed orchards.

Orchard	Number of units sampled			
	Clones	Trees	Cones	Mean % cones infested
McNair (loblolly pine)				
1969 1/	20	--	--	9.48
1970	20	245	21,477	11.66
Erambert (loblolly pine)				
1969 2/	--	--	--	--
1970	8	80	2,111	23.78

Table 2.--Continued

Orchard	Number of units sampled Clones	Trees	Cones	Mean % cones infested
Scott Paper Company (slash pine)				
1969	32	60	--	17.82
1970	44	249	--	33.69

1/Data were taken from International Paper Company's records which contained information on clones only and represented cones infested by any insect species.

2/This orchard did not produce enough cones in 1969 to obtain an adequate sample.

Mean coneworm infestation rates of 2nd-year cones collected from 20 clones (245 trees) of loblolly pine in the McNair Orchard were analyzed with a completely random design (CRD). An F test showed that the variance in infestation rates among the 20 clones was significant at the p<.01. When the mean infestation rates were compared with Kramer's extension of Duncan's new multiple range test (DNMRT), it was shown that a group of 9 clones showed signs of resistance, and a group of 2 clones showed signs of susceptibility to coneworm infestation when compared to all clones screened in the orchard (Table 2).

Differences in the mean coneworm infestation rates of the 2nd-year cones of 8 clones (80 trees) of loblolly pine in the Erambert Orchard were analyzed with a CRD. Variance among the means was shown to have a significant F value at the p<.01. When all the means were compared with Kramer's extension of DNMRT, a group of 5 clones appeared resistant and a group of 3 clones appeared susceptible to coneworm infestation (Table 2).

Differences in the mean coneworm infestation rates of 2nd-year cones collected from 44 clones (249 trees) in the Scott Paper Company Orchard in 1970 were analyzed with a CRD. These differences were also analyzed with a CRD from 2nd-year cones collected from 19 of the same clones (45 trees) in 1969. F tests showed that variance among the clones in each set of data were significant at the p<.01. When Kramer's extension of DNMRT was used to test for homogeneity among the means in the 1969 and the 1970 data, it was shown that 5 clones appeared consistently resistant and 2 clones appeared consistently susceptible to coneworm infestation when compared to all clones screened in the orchard (Table 2).

Table 2.--Results of preliminary screening for variable susceptibility to coneworm attack in 3 clonal pine seed orchards.

Orchard	Number of clones	
	Susceptible	Resistant
McNair (loblolly pine)	2	9
Erambert (loblolly pine)	3	5
Scott Paper Company (slash pine)	2	5

It is apparent from data obtained on the infestation rates of cones by the coneworm that differences in susceptibility do exist among the clones in each orchard. Within each orchard some clones appear resistant, and some susceptible.

Trees in each of the clones that appear to possess resistance should now be screened more intensively under controlled population densities of the coneworm. If inheritable resistance is definitely established among the clones in the orchards, the agencies involved will have to decide if these characteristics are worth further incorporation into the genetic stock.

LITERATURE CITED

Merkel, E. P., A. E. Squillace and W. G. Bengtson. 1965. Evidence of inherent resistance to Dioryctria infestation in slash pine. Proc. 8th S. Conf. Forest Tree Impr. 96-99.

Sartor, C. F. and W. W. Neel. 1971. Impact of Dioryctria amatella on seed yields of maturing slash and loblolly pine cones in Mississippi seed orchards. J. Econ. Entomol. 64(1): 28-30.

DISTRIBUTION AND INCIDENCE OF *LASPEYRESIA* SPP. SEEDWORM INFESTATION IN VIRGINIA, LOBLOLLY AND SHORTLEAF PINE CONES IN THE SOUTHERN STATES

B. H. Ebel [1]

In studies of the effects of insects on seed crops of southern pines one of the most difficult tasks is determining whether or not a specific insect, or insect group, is truly important. To date extensive surveys to evaluate relative importance of the various known insect pests of "flowers" and cones have been impractical both in terms of manpower available and of sampling procedures. Widespread reports of obvious damage or prevalance of certain insect species, such as *Dioryctria* spp. coneworm damage or seed bug, *Leptoglossus* and *Tetyra*, adults have served to justify research efforts. Less noticeable insects present a greater problem. One such group is the seedworms, *Laspeyresia* spp. Most of you are undoubtedly aware of the seed damage caused by the larvae of these small moths. However, neither the moths nor their larval seed destruction are readily observed. The larvae do, nevertheless, remain overwinter in the axes of open second-year cones. This habit provides one an opportunity for sampling from a single easily-recognized host over an ample time period of about 6 months (October-March).

Since relatively little was known of either the distribution or prevalence of seedworms in loblolly, shortleaf and Virginia pines we decided that a southwide study of the *Laspeyresia* infestations of these pine species would be both worthwhile and practical. To this end we enlisted the cooperation of federal, state and private industry personnel over a two-year period -- 1967-1968.

PROCEDURES

Cooperators were provided with simple data sheets to accompany cone collections. These provided records of collection location and such information as stand age and composition. Each cooperator was asked to provide 150 cones of each of the three pine species as available. Precise collection methods were left to the discretion of the collector. Cones were sent by various commercial transportation since during the overwinter period there was little hazard of insect mortality such as often occurs among insects shipped during warm weather.

Upon receipt of each collection a 20-cone sample was removed. The cones in this pre-rearing sample were dissected to detect the presence of *Laspeyresia* spp. infestation and the extent of such infestation in terms of numbers of cones infested, number of larvae per cone and number of seed destroyed per larva. The remaining cones of each collection were placed in chicken-wire or hardware-cloth "envelopes" and overwintered outdoors under a shortleaf pine canopy. Before anticipated moth emergence the cones were brought into an insectary and caged in suitably-sized cardboard boxes and lard cans fitted with glass collection jars. Emerging moths and parasites were attracted to the light through the jars hence readily collected. During the moth emergence period, late April-June, moths, and parasites, were collected daily from the jars. After emergence ceased all lots of cones which showed insect presence in the pre-rearing samples and/or from which moths emerged were held for another year because certain *Laspeyresia* spp. are known to diapause as larvae. The cones were again overwintered outdoors.

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[1] The author is research entomologist at the Forest Sciences Laboratory, which is maintained at Athens, Georgia, by the Southeastern Forest Experiment Station, Forest Service, U. S. Department of Agriculture

RESULTS -- DISCUSSION

Cooperation in this study proved to be very effective. In all 115 usable collections of 1967 crop cones were provided and 94 of 1968 cones. Of these, 90 were of loblolly pine, 73 of shortleaf pine and 46 of Virginia pine. Pre-rearing samples indicated that of 1967 loblolly collections 75 percent contained infested cones, and in 1968 87 percent were infested. Similarly collection infestation was 33 percent in 1967 and 26.5 percent in 1968 for shortleaf and 29 percent in 1967 and 32 percent in 1968 for Virginia pine cones.

Infestation in terms of the number of larvae per infested cone averaged 1.5 per loblolly cone, 1.4 per shortleaf cone, and 1.5 per Virginia pine cone in 1967. In 1968 cone collections about the same per cone infestation rate occurred, 1.75, 1.3 and 1.1 larva per cone for loblolly, shortleaf and Virginia pine respectively. From the data just presented one might consider that loblolly pine cones were heavily infested, and that control measures for *Laspeyresia* spp. might be warranted. However, it merely demonstrates the widespread occurrence of seedworms in loblolly pine as compared to the other two pine species. We need to consider the infestation rate on the basis of overall percentage of infested cones and the extent of seed destruction within cones before drawing conclusions. Loblolly pine was found to be again much more frequently infested than shortleaf or Virginia pines. For loblolly pine in 1967 the overall percentage of cones infested was 17 and in 1968 it was 17.5 percent. This contrasts with a very light infestation rate of 2.1 and 2.4 percent for shortleaf cones, and 5.4 and 2.7 percent for Virginia pine cones for 1967 and 1968 respectively. As we have already seen the average number of larvae per infested cone was similar for all three species ranging from about 1-2 larvae per cone.

Let us now look at the number of seed destroyed by each larva. Another convenient factor in *Laspeyresia* seed damage is the fact that infested seed tends to adhere within the open cones rather than to drop out. Counts of such seed were made from which we arrived at estimates of the number of seed destroyed per matured larva found. For loblolly pine this estimate was 6.2 seed per larva. The average for shortleaf pine was also 6.2 and for Virginia pine 7.4 seed destroyed per larva. These figures compare quite well with a 5-7 seed per larva figure reported by Merkel (1967) for *L. anaranjada* Miller in slash pine. Coyne (1968) reported an average of 4 longleaf pine seed destroyed by each *L. ingens* Heinr. but on a small sample (23 cones) he attributed 10-15 slash pine seed per larva for the same insect. Kraft (1968) reported an average of about 10 jack pine seed per larva for *L. toreuta* (Grote). In view of these estimates our figures seem somewhat conservative.

If we now apply our estimates of per cone infestation and per larva seed loss, we can arrive at a calculation of the total seed loss, for example, of the 1968 loblolly crop, based on our sampling. First, we had an overall cone infestation rate of 17.5 percent; second, we found an average of 1.75 larvae per infested cone which ate 6.2 seed per larva. If we consider 40-50 seed as a reasonable average of filled seed per cone as reported by Wakeley (1954) we can readily calculate the effect of seedworms on the 1968 loblolly seed crop as represented by our collections. To simplify, let me use 50 seed per cone as the expected average number of filled seed. First let us consider a sample of 1,000 cones. Of these we predicted 17.5 percent to be infested. Hence 175 cones would be subject to seed injury. Using the figures 1.75 (larvae per cone) x 6.2 (seed per larva) x 175 (infested cones expected) I arrive at a figure of 1,899 seed destroyed by *Laspeyresia*. Anticipated seed yield for 1,000 cones would be 50 x 1,000 = 50,000 seed. Dividing we find the estimated seed loss from *Laspeyresia* spp. to be 3.8 percent of total seed yield. The figures for 1967 loblolly collections would obviously be in a similar range since overall averages were similar. It would be questionable, I believe, that a 3.8 percent seed gain would be considered sufficient to justify routine control efforts, even in seed orchards. It would, however, be logical for a seed orchardist to check local trends in seedworm populations by sampling cones following seed harvest. Obviously the risk of seed loss of shortleaf or Virginia pine to *Laspeyresia*, based on our data, should be considerably less. It seems hardly worth consideration.

Before concluding I would like to add a few comments on the species of seedworms we reared, and on the extent of diapause as it occurred in our rearings. First, overall, the most prevalent species was *Laspeyresia toreuta*. Of over 500 reared specimens identified by Dr. D. R. Davis of the U. S. National Museum about 4/5 were this species. With rare exceptions the moths reared from Virginia and shortleaf pine were this species. On loblolly pine, however, *Laspeyresia ingens* also occurred, in about a 1:3 overall ratio, with *L. toreuta*. No obvious pattern seemed to exist in its occurrence, such as the presence of other host pines in the collection areas.

In rearing from both 1967 and 1968 collections about 20-25 percent of the *Laspeyresia* spp., and of a parasite, *Phanerotoma fasciata* Provancher, emerged the second summer following cone collection, indicating that under our rearing conditions diapause was prevalent. Such diapause has been reported previously for both *L. ingens*, Coyne (1968) and *L. toreuta*, Kraft (1968) but to a lesser extent.

LITERATURE CITED

Coyne, J. F. 1968. *Laspeyresia ingens*, a seedworm infesting cones of longleaf pine. Ann. Entomol. Soc. Amer. 61: 1116-1122.

Kraft, K. J. 1968. Ecology of the cone moth *Laspeyresia toreuta* in *Pinus banksiana* stands. Ann. Entomol. Soc. Amer. 61: 1462-1465.

Merkel, E. P. 1967. Life history of the slash pine seedworm, *Laspeyresia anaranjada* Miller (Lepidoptera: Olethreutidae). Fla. Entomol. 50: 141-149.

Wakeley, P. C. 1954. Planting the southern pines. USDA For. Serv. Agr. Monogr. 18, 233 pp.

AN ASSESSMENT OF COTTONWOOD TWIG-BORER ATTACKS [1]

R. A. Woessner [2] and T. L. Payne [3]

Commercial production of eastern cottonwood (Populus deltoides Bartr.) in plantations on agricultural soils in Brazos and Burleson Counties, Texas, is economically prohibitive because of severe attacks by cottonwood insects. The stunting and deformation of young trees caused by the cottonwood twig-borer (Gypsonoma haimbachiana Kft.) is especially serious. Morris (1967) rates this as the most destructive of the insects that damage young cottonwood. The degree of damage currently being sustained in Brazos River bottom non-irrigated plantations confirms the destructive ability of this insect.

This investigation was undertaken to determine (1) whether any of the clones currently under test have a low incidence of twig-borer attack, (2) what relationship there is between clonal form and incidence of twig-borer attack, and (3) what relationship there is between clonal volume production and incidence of twig-borer attack.

In addition, the high rates of attack found in plantations prompted sampling of naturally regenerated trees of the Brazos and Colorado river bottoms to determine whether natural stands sustained the same high levels of attack.

METHODS

Four cottonwood plantations and six naturally regenerated areas were utilized in this study. The intensity of twig-borer attacks was determined during the dormant season in three non-irrigated clonal test plantations on the Brazos River bottom. Two of these were one-year-old plantations established near the city of Mumford, in Brazos County, on contrasting soil types--one on the more productive soil for cottonwood, a Norwood clay loam, and one on the lesser productive soil, a Miller clay. The third was a two-year-old plantation on a Norwood clay loam soil on the Texas A&M University farm in Burleson County, Texas.

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[2] Associate geneticist with the Texas Forest Service and assistant professor at Texas A&M University, College Station, Texas.

[3] Assistant professor in the Department of Entomology at Texas A&M University, College Station, Texas.

In order to rate the intensity of attack in the three plantations, the sampling procedure consisted of removing the leader of a randomly chosen ramet of each of 36 eastern cottonwood clonal selections and of one hybrid, NE-316 P. cv. Charkowiensis X P. cv. Robusta, in two replications in each of the three plantations during the dormant season. The terminal 14 inches of each of the 222 leaders was scored for the number of twig-borer attacks. In sampling from the naturally regenerated areas, five 14-inch leaders were collected at each of three sub-sample points on both the Brazos and Colorado River bottoms.

The counts of the twig-borer attacks were analyzed by transforming the counts to the square root of the original value plus 1, $X = \sqrt{X+1}$. The transformed counts were then subjected to an analysis of variance. A nested analysis (Table 1) with equal sample, subsample, and specimen numbers was used to compare the Colorado and Brazos natural areas with the three Brazos clonal plantations. Samples in this study were Brazos River plantations, Brazos River natural stands, and Colorado River natural stands. In order to have only five terminals per plantation, five random samples were chosen from among the 74 terminals collected per plantation. Sub-sample areas on the Brazos River were areas near the cities of Mumford and Bryan and an area near the Texas A&M University farm. Sub-sample areas on the Colorado River were near the cities of Bastrop, LaGrange and Smithville.

Table 1.--Nested analysis of variance for number of twig-borer attacks per 14-inch terminal

Source	df	ss	ms	F 1/
Samples 2/	2	30.00	15.00	14.4**
Sub-samples within samples	6	6.24	1.04	5.2**
Trees within sub-samples	36	7.40	.20	

1/ **Statistically significant at the .01 level.

2/ Samples were Brazos River plantations, Brazos River natural stands, and Colorado River natural stands.

A factorial analysis was used for the clonal data. The counts of the clones in the plantation were analyzed separately by plantations and then combined over plantations, since the error terms were found to be homogeneous.

Data on form was obtained only in the two-year-old University farm plantation. Four ramets of each clone were subjectively rated on a scale from 0 to 5; a 0 indicated no apparent damage and a 5 many dead tips and multiple leaders.

Volume production was obtained for eight clones growing in a four-year-old irrigated plantation on the Texas A&M University farm in the Brazos River bottom.

RESULTS AND DISCUSSION

Plantations versus Natural Stands

Comparison of the sample means by the Duncan test indicated the Colorado River samples to have a significantly lower level of attack than either the Brazos plantations or the Brazos natural stands (Table 1). The mean number of attacks per leader (Table 2) for the three Brazos River plantations was 12. It differed by little from the value of 10 for the three Brazos Rivernatural stands. However, the attack on the Colorado River bottom was much lower, with the mean for the three Colorado River stands at only 2 attacks per terminal.

Table 2. Mean number of twig-borer attacks per 14-inch leader for the three samples

	Mean number of attacks per 14-inch terminal 1/
Brazos River Plantations	12
Brazos River Natural Stands	10
Colorado River Natural Stands	2

1/ Means not connected by the same vertical line differ significantly at the .01 level by the Duncan test.

The current explanation offered for the discrepancy between the attack levels is that the high level of agricultural pesticides used in the Brazos Bottom keeps the twig-borer predator population at a low level. This explanation needs to be checked experimentally.

Significant differences (Table 1) also existed among sub-samples within samples in the Colorado River natural stands and the Brazos plantations. The mean attack of 5 for the LaGrange sub-sample from the Colorado River (Table 3) was significantly greater than the mean of one for the other two sub-samples. The mean of 9 for the Mumford Miller clay plantations was significantly lower than the mean of 15 for the Mumford Norwood clay loam. There is at present no factual explanation for the differences found among the sub-samples.

Table 3.--Mean number of twig-borer attacks per 14-inch leader for each sub-sample

	Mean number of attacks per 14-inch terminal 1/
Brazos River Plantations	
Mumford Norwood soil	15
University farm Norwood soil	13
Mumford Miller soil	9
Brazos River Natural Stands	
Mumford Norwood soil	12
University farm Norwood soil	11
Bryan Norwood soil	8
Colorado River Natural Stands	
LaGrange	5
Bastrop	1
Smithville	1

1/ Means not connected by the same vertical line differ significantly at the .01 level by the Duncan test.

Clonal Differences in Number of Attacks

Significant differences among clones were indicated for number of attacks (Table 4). The range in mean number of attacks per terminal was from 1.5 to 16. The frequency of clones having various levels of attack is given in Table 5. Only one of the 37 clones has less than two attacks per terminal. Comparing the means by the Duncan test, only the hybrid NE-316 with a mean of 1.5 is found to have a lower incidence of attack than the other clones.

Table 4.--Clonal analysis of variance combined over plantations for mean number of twig-borer attacks per 14-inch terminal

Source	df	ss	ms	F 1/
Plantations	2	23.21	11.61	1161.0**
Replications in plantations	3	.03	.01	
Clones	36	38.25	1.06	3.3**
Clones X Plantations	72	23.16	.32	2.5**
Pooled error	108	13.63	.13	

1/ ** Statistically significant at the .01 level

Unfortunately, NE-316 does not outgrow native cottonwood of Texas origin. In the four-year-old irrigated plantation used for data on volume production, native nursery-run cottonwood averaged 40.0 feet in total height, NE-316 only 35 feet (Woessner, 1970). Maisenhelder (1970) also finds that eastern cottonwood selections are outgrowing hybrids on southern sites. He points out that these hybrids originated and were originally selected and tested in more northern latitudes than where they are now being grown. This could be one reason why native selections outgrow them.

Table 5.--Frequency table of nearest whole number of twig-borer attacks combined over plantations per 14-inch terminal for the 37 clones

Number of attacks	Clonal frequency	Relative Frequency %
2	1	3
9	1	3
10	3	8
11	4	11
12	9	24
13	5	13
14	7	19
15	6	16
16	1	3
	37	100

Maisenhelder (1970) also reported native cottonwood to be more resistant to pests than the hybrids he tested. However, one clone of Mississippi delta origin which he tested, Rosedale 8, was also included in this study, and it averaged 11 attacks per terminal in these tests as opposed to the 1.5 for the hybrid NE-316.

A significant clone-by-plantation interaction is also indicated by the analysis of variance results (Table 4). A statistically significant interaction could be detected by the analysis of variance when a true interaction, i.e., changing of clonal ranking from plantation to plantation, does not really exist. Robertson (1959) pointed out that an interaction could arise for two reasons, one being a changing of ranking and the other being that the clonal components of variance are different in the different environments. In this instance, the largest and smallest clonal components do differ by about 40 percent. Also, come changing of rank of the clones from plantation to plantation does take place. However, this could be due to too few samples per clone per plantation rather than indicative of a true interaction. Until further investigations can confirm or disclaim the interaction, it should be suspect.

Of most practical significance is the fact that the hybrid NE-316, the only clone significantly less attacked by the twig-borer, does not change ranks and remains relatively stable across the environments. The lowest level of attack, .5 per ramet, occurred on the Mumford Miller clay. The highest, 3.0 attacks per ramet, was on the Mumford Norwood soil planting.

Relationship between Form, Volume Productivity, and Number of Attacks

Obvious differences in form and in volume production show up among the 36 native eastern cottonwood clones. NE-316 was not included in these investigations because of the low level of attack. Since twig-borer attacks stunt and deform trees, it would not be unreasonable to expect that well-formed, high-volume producers would have a low intensity of attack.

An investigation of the relationship between form and intensity of attack was carried out in the two-year-old planting on the University farm. The trees were scored subjectively for form on a scale from 1 to 5, 5 being the poorest form. Two of the better formed clones of above average growth, S7C1 and S13C13, are shown in Figures 1 and 2. Clones of much poorer form, but also of above average growth, S7C8 and S13C21, are shown in Figures 3 and 4. The intensity of attack for these clones is given in Table 6. For these four clones, there is an inverse relationship between form and intensity of attack--the better the form, the higher the level of attack. A simple linear correlation between the mean form score for the 36 clones and the mean number of attacks failed to bear out any statistically significant relationship, either positive or negative. The simple linear correlation was extremely low--.03.

Table 6. Mean number of twig-borer attacks per 14-inch terminal for two well-formed and two poorly-formed clones

	Mean number of attacks per 14-inch terminal [1]
S13C13	12.3
S13C21	8.7
S7C1	16.3
S7C8	12.5

[1] Six terminals per clone; 3 plantations, 1 ramet in each of 2 replications per plantation.

The relationship between volume production and intensity of attack was investigated for eight of the native cottonwood clones, utilizing the mean number of attacks for the three one- and two-year-old plantations and the clonal volume production at age 4 in the Texas A&M University farm irrigated plantation. The simple linear correlation was fairly high, .60, but still insignificant. At any rate, S7C1, the clone with the highest average rate of attack in the three younger non-irrigated plantations is producing the greatest volume in the four-year-old irrigated plantation.

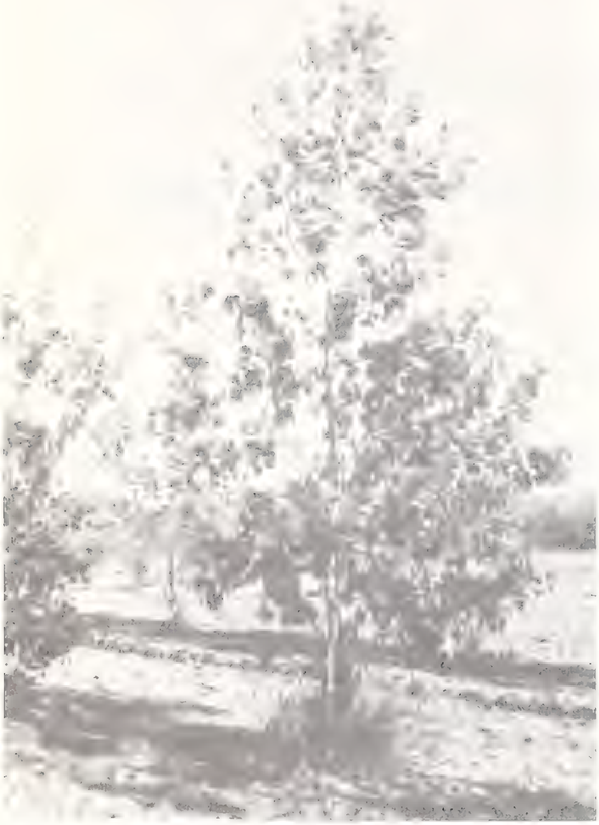

Figure 1. Clone S7C1

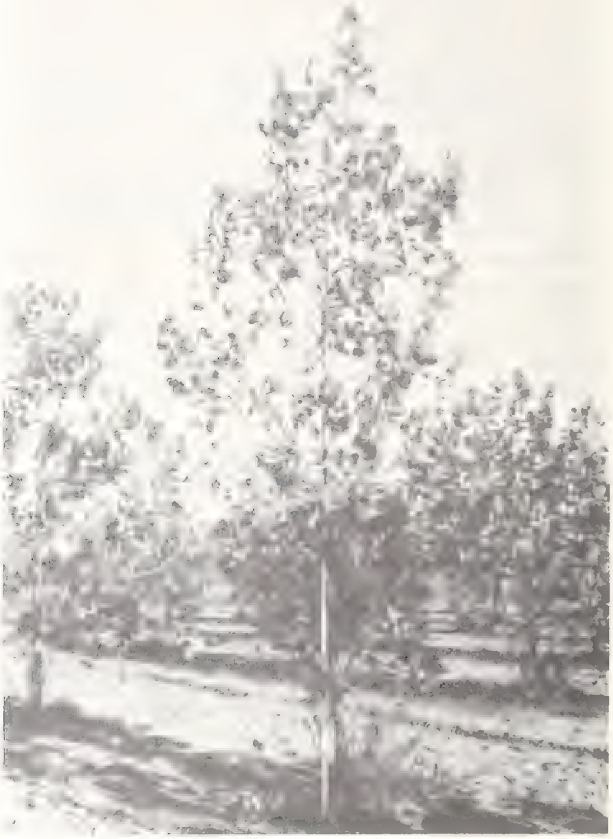

Figure 2. Clone S13C13

Clones S7C1 and S13C13 maintain excellent apical dominance in an area subject to heavy twig-borer infestations.

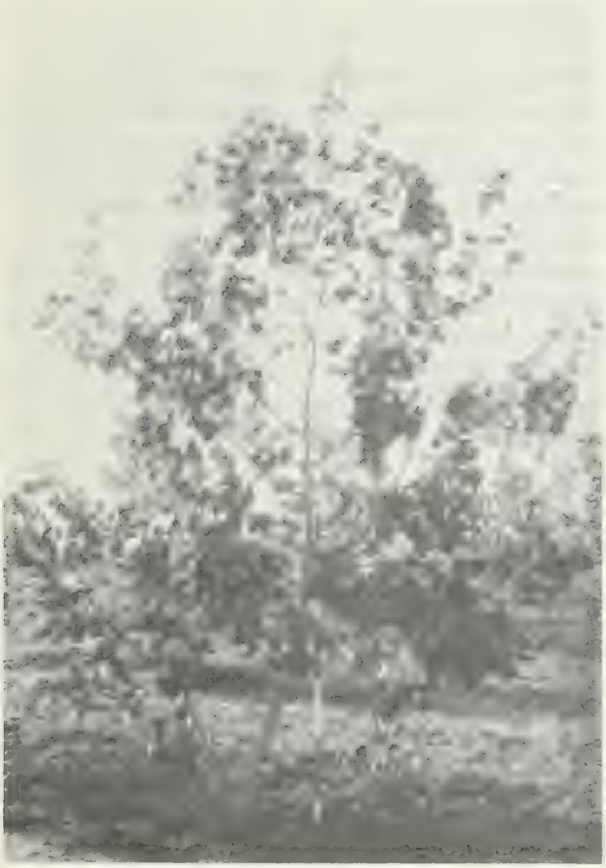

Figure 3. Clone S7C8

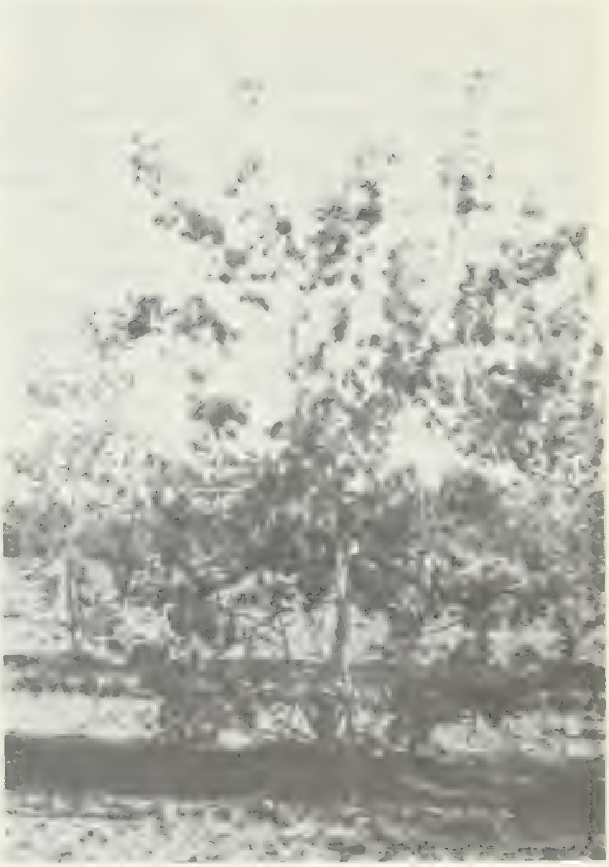

Figure 4. Clone S13C21

Clones S7C8 and S13C21 were badly deformed when grown in an area subject to heavy twig-borer infestations.

The results obtained for the form and volume investigations turned out somewhat differently than originally hypothesized. Among the clones tested, an inverse relationship between form, volume production and intensity of attack does not exist. Apparently, some clones if growing fast enough have reasonable form and produce high volumes in spite of the twig borer.

SUMMARY AND CONCLUSIONS

An investigation of intensity of cottonwood twig-borer attack in three sample areas, Brazos River bottom natural stands, Brazos River bottom plantations, and Colorado River natural stands, indicated there to be essentially no difference in attack levels in the Brazos. Brazos natural stands averaged 10 attacks per terminal as opposed to 12 for the plantations. The attack level in the Colorado was significantly lower, being only 2 attacks per terminal. An appealing but as yet unproved hypothesis is that the high twig-borer population in the Brazos is tied in with land-use patterns. The Brazos bottom is intensely farmed, and agricultural pesticides are in wide use. It could be that pesticides have more effect on twig-borer predators than on the twig-borers and thus have led to an epidemic-like situation in the portions of the Brazos River bottom studied.

The investigation of differences in intensity of attack among the clones indicates that all 36 eastern cottonwood clones are heavily attacked. The native material ranged from 9 to 16 attacks per 14-inch terminal. These differences among the native clones could not be shown to be statistically significant. NE-316, a hybrid with an average of 1.5 attacks per terminal, was significantly less attacked than all of the native cottonwood.

An investigation of the relationship between tree form and intensity of attack with the native cottonwood clones indicated certain clones were able to maintain a reasonable timber form even though sustaining high levels of twig-borer attack. An investigation of the relationship between volume production under irrigated conditions and intensity of attack under non-irrigated conditions indicated native clones having above average rates of attack under non-irrigated conditions are capable of high volume production when grown under irrigated conditions.

Possibly, native cottonwood can be found that will be relatively resistant to borer attack and thus capable of maintaining economical growth on non-irrigated sites. If not, species hybridization as suggested by Schreiner (1970), with native cottonwood as one of the parents, may well be the most reasonable approach if cottonwood is to be grown commercially and economically in Texas. All hybrids so far tested in Texas, including NE-316, grow slower than the better native cottonwood. However, this is not an indication of the true potential of hybridization, because currently available Populus hybrids were not selected for their performance in the south. A slower growth rate could certainly be tolerated in insect resistant hybrids capable of growing without irrigation. The savings in irrigation costs and insect protection would more than offset the loss in growth.

LITERATURE CITED

Maisenhelder, L.C. 1970. Eastern Cottonwood Selections Outgrow Hybrids on Southern Sites. J. of Forestry 68: 300-301.

Morris, Robert C. 1967. Biology of *Gypsonoma haimbachiana* (Lepidoptera: Olethreutidae), a twig borer in eastern cottonwood. Ann. Entomol. Soc. Amer. 60: 423-7.

Robertson, A. 1959. Experimental design on the measurement of heritabilities and genetic correlations. Biometrical Genetics. Pergamon Press, New York.

Schreiner, Ernst J. 1970. Genetics of eastern cottonwood. USDA Forest Serv. Res. Pap. Wo-11, 24 p.

Woessner, R.A. 1970. Growth, volume and dry weight differences among 4-year-old Populus clones grown under irrigation. Presented at First North American Forest Biology Workshop, Aug. 5-7, Mich. State Univ., East Lansing, Michigan.

WILLOW CLONES DIFFER IN SUSCEPTIBILITY TO COTTONWOOD LEAF BEETLE

W. K. Randall[1]

Abstract.--Amount of defoliation by the cottonwood leaf beetle on 1-year-old trees from 37 clones of black willow ranged from 21 to 95 percent. Male clones of black willow were damaged significantly more than female clones. Two clones of *Salix babylonica* X *S. alba* and three of sandbar willow were very lightly attacked. The only clone of *Salix* X *argentinensis* was 52 percent defoliated.

Larvae of the cottonwood leaf beetle (*Chrysomela scripta* F.) defoliate willows as well as poplars. When numerous, these insects may remove all leaves and severely damage terminal shoots. The ease with which black willow (*Salix nigra* Marsh.) can be vegetatively propagated and its rapid growth on wet sites makes it a candidate for genetic improvement, and results of the exploratory study reported here indicate that clones of black and other willows vary considerably in their resistance to defoliation by the cottonwood leaf beetle.

MATERIALS AND METHODS

During March 1970, cuttings were taken from 30 randomly selected black willow trees that were 30 to 40 years old and from 13 that were 2 or 3 years old. At the same time, cuttings were taken from three sandbar willows (*Salix interior* Rowlee) 2 or 3 years old. This species is classed as a shrub or small tree; it may reach a height of 30 feet (Vines 1960). Also included in the experiment were two clones of the cross *Salix babylonica* L. X *Salix alba* L. (Ragonese and Alberti 1965) and one of *Salix* X *argentinensis* 'Mestizo Usoz,' which is probably a natural hybrid of *Salix babylonica* and *Salix humboltiana* Willd. These hybrids were sent to the Southern Hardwoods Laboratory in June 1965 by Dr. Arturo Ragonese of the National Center of Agricultural Investigations at Cestellar, Argentina. They have been maintained in a nursery, and for the present test 1-year-old cuttings were taken from rootstocks that were 2 years old. A total of 49 clones were included in the experiment.

Unrooted cuttings 18 inches long were planted in late March 1970 on the Delta Experimental Forest near Greenville, Mississippi. The design was a randomized complete block with six replications of single-tree plots. Spacing was 10 by 10 feet.

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[1] The author is Associate Silviculturist at the Southern Hardwoods Laboratory, which is maintained at Stoneville, Mississippi, by the Southern Forest Experiment Station, USDA Forest Service, in cooperation with the Mississippi Agricultural and Forestry Experiment Station and the Southern Hardwood Forest Research Group.

The site was cleared during the fall prior to planting. Soil is Sharkey clay, and the site is low; water covers much of the area during winter and early spring. The recommendations of McKnight (1970) for establishing cottonwood plantations were followed in planting and cultivating.

The original purpose of the study was to observe growth of willows on a heavy clay site, but cottonwood leaf beetles caused heavy defoliation during the summer of 1970.

On September 30, 1970, before any trees had recovered from the attacks, heights were measured to the nearest 1/10 foot and the amount of defoliation was estimated to the nearest 10 percent. A defoliation rating of from 1 to 10 was assigned, with 1 representing less than 10 percent loss of foliage, and 10 representing more than 90 percent.

Six clones that consisted of cuttings from mature black willows did not root satisfactorily; they were excluded from the analysis. Remaining were balanced data on 37 black willow clones, three sandbar willow, and three hybrids. Analyses of variance were calculated to find differences among means that were statistically significant at the 0.05 level. A simple correlation was calculated between clone means for defoliation and height.

RESULTS

Average height of all trees in the plantation was 6.0 feet at the end of the first growing season. The highest clone averages were for sandbar willows, which averaged 9.4 feet tall. Slightly less tall at 8.6 feet were the two clones of the hybrid *S. babylonica* X *S. alba*. The hybrid clone *S.* X *argentinensis* was 6.1 feet tall. The range for clone means of black willow was 2.0 to 8.0 feet, and the mean was 5.6 feet. The black willow population was divided into three groups: male, female, and sex unknown. The average height for the clones of unknown sex was 7.0 feet, significantly taller than either the male or female groups. Male clones of black willow were slightly but not significantly taller than female clones at the end of the first year. All other group means were significantly different from each other. Averages and ranges for height and defoliation are presented in table 1.

Amount of defoliation by the cottonwood leaf beetle varied significantly by species and clone. The overall average defoliation was 63 percent, and clone means ranged from 5 to 95 percent. Sandbar willow and the two interspecific hybrid clones (*S. babylonica* X *S. alba*) received the least damage (less than 10 percent). There was no significant difference between these two groups. The other interspecific hybrid clone, *S.* X *argentinensis* was 52 percent defoliated. The average for all black willow clones was 69 percent, and clone means ranged from 21 to 95 percent. Significantly less attack occurred on the 11 female clones than on the 13 male clones (55 percent versus 78 percent). The group of 13 clones for which the sex was unknown was intermediate between and not significantly different from either the male or the female clones. The simple correlation between defoliation and height ($r = 0.21$) was not statistically significant. Broad-sense heritability for resistance to defoliation, based on clone means, was $h^2 = 0.95$.

Table 1.--Variation among willow clones in first-year height and in defoliation by the cottonwood leaf beetle

Species or hybrid	Number of clones	Height		Defoliation	
		Average	Range of clone means	Average	Range of clone means
		Feet		Percent	
Black willow (*Salix nigra*)	37	5.6	2.0-8.0	69	21-95
Male	13	5.0e	4.3-5.7	78a [1]	52-95
Female	11	4.6e	2.0-5.9	55b	21-80
Sex unknown	13	7.0c	5.9-8.0	71ab	40-92
S. X *argentinensis*	1	6.1d	--	52b	--
Sandbar willow (*S. interior*)	3	9.4a	8.9-9.8	9c	8-10
S. babylonica X *S. alba*	2	8.6b	8.6-8.7	5c	5- 5
All clones	43	6.0	2.0-9.8	63	5-95

[1] Group means with the same letter are not significantly different by Duncan's multiple range test at the 0.05 level.

DISCUSSION

Newly developing larvae of the cottonwood leaf beetle must have a readily available source of food, since they cannot move more than a few inches. Certain clones may be more resistant to the leaf beetle because they are unsuitable for larval development, or because they are unacceptable to the ovipositing female. Resistance may be due to a combination of these factors or to other physiological or morphological characters of the host.

The black willow clones of unknown sex may have grown taller than either the female or male clones because of the physiological condition of the cuttings. Male and female cuttings came from the crowns of trees 30 to 40 years old, whereas cuttings from the group of unknown sex were taken from seedlings that were 2 to 3 years of age. In cottonwood, cuttings from 1- to 3-year-old seedlings have better survival and first-year growth than cuttings from the crowns of older trees.

Willows that were lightly attacked during the fall of 1970 were also lightly attacked in the spring of 1971. The tops of many trees that were heavily attacked died back during the late fall and winter of 1970-71. During the spring of 1971 crown deterioration continued, and many of the heavily attacked clones were either dead or dying. This die-back may be caused by a combination of severe beetle damage and an unknown pathogen, but attempts to isolate a pathogen have been unsuccessful.

Although the results apply only to a single group of clones on a single site, heritability was very high for resistance to the leaf beetle. Certainly, research to confirm these results and to determine the factors responsible seems justified.

LITERATURE CITED

McKnight, J. S. 1970. Planting cottonwood cuttings for timber production in the South. USDA Forest Serv. Res. Pap. SO-60, 17 pp. South. Forest Exp. Stn., New Orleans, La.

Ragonese, A. E., and Alberti, F. R. 1965. Nuevos sauces hibridos forestales obtenidos en la Republica Argentina. IDIA-Supl. For. 65-74.

Vines, R. A. 1960. Trees, shrubs and woody vines of the Southwest. 1104 pp., illus. Univ. Tex. Press, Austin.

HERITABILITY - GEOGRAPHIC SELECTION

Banquetees

GEORGIA SYCAMORE SEED SOURCES IN MISSISSIPPI PLANTINGS: SITE ADAPTABILITY A KEY FACTOR

Daniel M. Schmitt and Charles D. Webb[1]

Abstract.--When seedlings from five sources along the Chattahoochee and Apalachicola Rivers were planted on a moderately good river-bottom site in southern Mississippi, those from Coastal Plain sources leafed out earlier in spring and grew more rapidly than those from more northerly sources in the Piedmont and mountains. It was therefore inferred that sycamore foliation date is under strong genetic control. Third-year heights differed significantly among seed sources and among families within sources, but the component of variance for sources was almost three times the size of the component for families within sources. On a poor site nearby, a genetically identical plantation was established with rooted cuttings from tops of the seedlings. Thirty-three families were common to both plantations. Family performance was not significantly correlated in the two plantations. The discrepancy may have been due to interactions between family and environment or between family and propagation method.

Sycamore (Platanus occidentalis L.) has silvical characteristics--including rapid growth, abundant seeding, and relative intolerance--which lend themselves to large-scale plantation management. It is not surprising, then, that forest geneticists have undertaken to determine the extent to which vigor components in native sycamore are heritable. Since sycamore has a broad geographic range in the eastern half of the United States (USDA Forest Service 1965), seed source adaptability to varying climatic and site regimes is a matter of immediate importance.

Fogg (1966) observed that trees from six widely separated sources varied in their response to a planting site near Baton Rouge, Louisiana. We report the performance, at two planting locations in Mississippi, of five seed sources from a short transect through Georgia and Florida.

METHODS

Seeds from ten randomly selected trees were collected in each of five stands along the Chattahoochee and Apalachicola Rivers. The two streams follow essentially a north-south course from the mountains of north Georgia to the Gulf of Mexico. The seed sources were 60 to 100 miles apart:

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[1] When the data were collected, Schmitt was Principal Plant Geneticist, Institute of Forest Genetics, Southern Forest Experiment Station, USDA Forest Service, Gulfport, Mississippi. He is now Assistant Director, Northeastern Forest Experiment Station, Upper Darby, Pennsylvania. Webb is Project Manager, Genetics, U. S. Plywood-Champion Papers, Inc., Athens, Georgia.

Seed source	Physiographic province	Elevation -Feet-
White County, Ga.	Blue Ridge Mountains	1400 - 1600
Douglas County, Ga.	Piedmont	700 - 800
Stewart County, Ga.	Upper Coastal Plain	150 - 200
Seminole County, Ga.	Upper Coastal Plain	50 - 100
Liberty County, Fla.	Lower Coastal Plain	< 50

Results of stratification and germination tests were reported by Webb and Farmer (1968).

Seeds were sown in an experimental nursery at Gulfport, Mississippi. The first planting was established during January 1967; the site was near Picayune, Mississippi, on land of the St. Regis Paper Company. The seedlings were top-pruned before being lifted, and the tops were subsequently rooted in the nursery and planted out at Gulfport in 1968. The planting design at both locations was a randomized block in which the families were restricted to and randomized within the parent seed source; sources were randomized within the replication. Four-tree row plots were employed in both plantings, with five replications at Picayune and four at Gulfport. The plantations were genetically identical to the extent that each family at Gulfport had 16 of the 20 genotypes planted at Picayune. Spacing between trees was 10 by 10 feet.

Forty families were represented at Picayune and 33 at Gulfport. White County was represented by five families at Picayune and four at Gulfport, Douglas County by eight and five families, and Seminole by seven and four families. Stewart and Liberty Counties each had 10 families in both plantations.

Sites.--The soil at the Picayune site is a rich, alluvial sandy slit underlain by gravel lenses. It is subject to moderately frequent spring overflows from the Pearl River. The Gulfport soil is a typically well-drained infertile Coastal Plain sand (Ruston series).

The two sites are 30 miles apart along a more or less east-west axis. There are no essential climatic differences. In August 1969, both plantings withstood hurricane-force winds that left some trees leaning permanently.

Measurements.--Survival, root-collar diameter, and total height were measured in the Picayune planting at the end of the first growing season. The following spring the dates of foliation were recorded twice weekly until the entire planting had leafed out. Foliation data were expressed as days since March 31, when the first observations were made. Both plantings were remeasured at the end of their third year in the field.

RESULTS

Survival.--At Picayune, survival was 97 percent after one year and 93.6 percent after three years. A Bartlett's test, following arc sine transformations of plot survival (Mosteller and Youtz 1961), showed that survival variances were not homogeneous. (All differences noted in this article are significant at the 0.05 level.) The mean square for families within sources was extremely low for the Seminole and Liberty sources, yet these two sources differed considerably, Seminole averaging 83.5 percent and Liberty 97.0 percent. From a practical standpoint, however, survival differences are trivial, and are unlikely to influence stand development.

Root-collar diameter and d.b.h. measurements at Picayune.--Separate analyses of variance of root-collar diameter by source and families within source disclosed no differences among sources; differences between families were significant only in the Seminole source. After three years, there were no differences among sources in d.b.h., but differences between families occurred in the Douglas and Stewart sources. Mean variances were homogeneous. Though source differences in d.b.h. were not significant, there was a noticable trend for diameter to increase from northern to southern sources:

Source	Mean d.b.h.
	-Inches-
White	2.6
Douglas	2.4
Stewart	2.8
Seminole	2.8
Liberty	3.0

Moreover, the source component of variation (0.0261) was about 1.5 times as large as the within-source component (0.0172).

Height in the Picayune planting.--When variances in first-year heights at Picayune were analyzed separately by source and families within source, differences among families were judged significant only within the Seminole and Stewart sources. Of the 10 tallest trees at age 1, six were from Liberty County, the most southern source. The average height of these 10 trees was 9.1 feet, almost twice the plantation average of 4.9 feet.

By the end of the third growing season significant source differences had appeared (table 1). Differences among families within sources also persisted, but the component for the sources was almost three times as large as the component for families within source. By Bartlett's test, mean variances were homogeneous.

Table 1.--Analysis of variance of third-year height and d.b.h. at Picayune, Mississippi

Source of variation	D.F.	Height	D.b.h.
		M.S.	M.S.
Blocks	4	36.3718	2.6613*
Sources	4	60.4171*	1.7688
Error I	16	13.2360	.6513
Families/sources	35	3.8091*	.2156*
Error II	140	1.7516	.1298
Source component, δ_s^2		1.1424	.0261
Families/source component, δ_{fs}^2		.4115	.0172

*Significant at the 0.05 level.

Mean plantation height after 3 years was 14.9 feet, and the 10 tallest trees averaged 22.7 feet. Eight of these 10 trees were from Liberty County.

Third-year height at Gulfport. The objective of the Gulfport planting was to determine the performance of genetically identical plantations on sites obviously differing in quality.

If heredity were the sole influence on height growth, a regression of the mean heights of the 33 families at Gulfport on the same 33 families at Picayune should have yielded a 45° line with a regression coefficient approximating 1.0. The actual coefficient for raw family means at both locations was 0.1591.

The simplest model for analysis over locations is: $X = \overline{u} + L + R_L + F + FL + e$. Here $\overline{u}$ is the population mean over both locations, R_L is replication within locations, F is family effect, FL is family × location interaction, and e is pooled residuals. In this simple model F subsumes source effects, and FL subsumes source × location effects.

In a combined analysis over both plantations, sources and families within sources differed significantly. The Picayune plantation was the cause of most of the differences, but there was also a significant interaction involving families within sources and locations.

Date of foliation at Picayune.--At Picayune, foliation date differed significantly between sources and among families within sources. When dates are plotted over the distances separating the sources, a clinal pattern emerges (fig. 1). If date of foliation at Picayune is plotted over date of last killing frost at the source (data from U. S. Department of Agriculture 1941), a clinal pattern is also obtained (fig. 2). Kaszkurewicz and Fogg (1967) analyzed growth initiation (defined as bud break) in sycamore from 39 locations throughout the species' range in the United States. They found it to be highly correlated with latitude, photoperiod, mean air temperature in the month of bud break, and last killing frost up to 33° N. latitude (the northernmost source in the present study, White County, is at 34° 30' N. latitude). They postulated that photoperiod and temperature and other factors, including genetic adaptation, were interrelated and conditioned the plant's response to the environment.

In the present study we do not have foliation information from the source locations, but it is striking that at Picayune the relation between foliation date and distances between sources in Georgia, and dates of last killing frosts at source locations, are precisely as would be predicted from Kaszkurewicz and Fogg's (1967) analysis of sycamore phenological data. Consequently we infer that date of foliation in this short transect along the Chattahoochee and Apalachicola Rivers is under strong genetic control.

In correlation analysis including all 40 families, with source disregarded, third-year height was negatively correlated with foliation date. Families foliating early were taller than families foliating late. Relationships within sources were inconsistent.

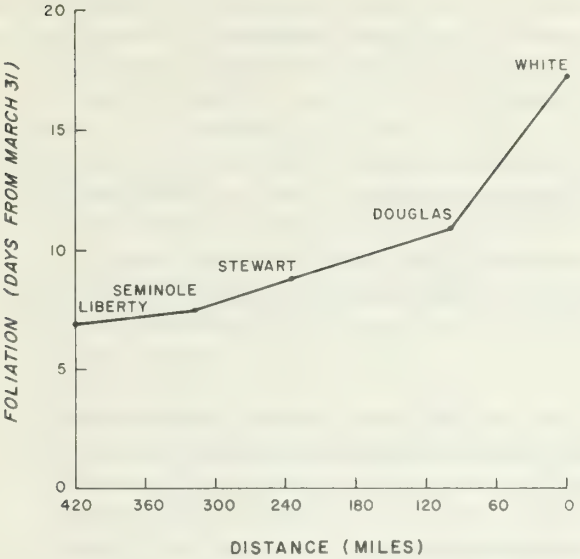

Figure 1.--Date of sycamore foliation in Mississippi as related to seed source distances from origin of the Chattahoochee River.

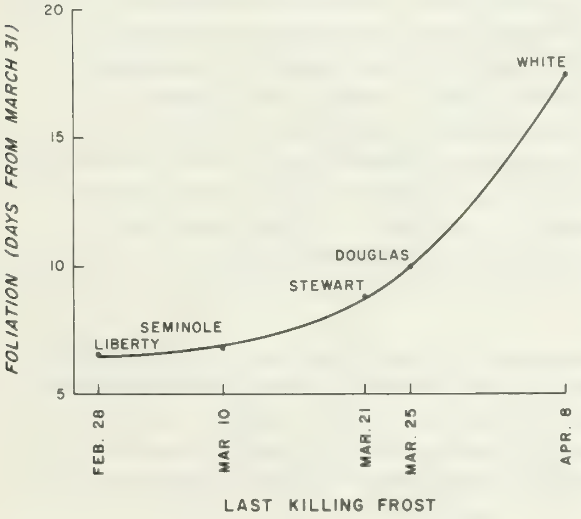

Figure 2.--Foliation dates in relation to last killing frost at the seed sources.

DISCUSSION

Two important features of the investigation bear on the development of research and breeding programs in sycamore. We have provided circumstantial evidence that date of foliation is under strong genetic control. Moreover, the sources which leafed out earliest at Picayune (Liberty and Seminole at the southern end of the transect) also had the greatest d.b.h. and total height at age 3. However, foliation dates and family heights varied within sources, and there seemed to be no relation within a source between foliation date and third-year height and diameter. Since there were at most 10 families per source, the evidence for lack of such a growth relation is not very convincing. Still, it is a matter deserving research, on the possibility that foliation date can be used as a guide for phenotypic selection.

The second important feature of the investigation was the comparison of third-year heights in two plantings differing in site and propagation method. The location effect, unconfounded by genetic differences between plantings, was 3.9 feet in favor of Picayune. This is a large difference for 3-year-old plantings, and it can be attributed mainly to the soils at the two sites. According to a subjective classification (Briscoe 1969, table on p. 8), the Picayune site would rate as moderately good and the Gulfport site as poor.

The rather drastic changing of family performance from one plantation to the next may be due to one or both of two factors: (1) a true genotype × environment interaction, (2) a family × propagation-method interaction. Webb (1970) reported a significant family × planting site interaction in sycamore, and Steinbeck (1970) found significant interactions of clones with nutrient levels. Data presented by Schmitt and Webb (1970) show similar family × location interactions in sweetgum. But the possibility remains that differences in rooting ability among clones may also occur among half-sib families of rooted cuttings; if so, they would contribute to an interaction between family and propagation method. With the present study design, it is not possible to determine which is the more accurate explanation.

Finally, analyses of the Picayune planting showed that source effects were increasing for diameter growth and, by age 3, were already significant for height. Moreover, source components of variation were larger than family components for both diameter and height at age 3. These results are in accord with unpublished data we have for sweetgum in the Mississippi Valley.

A comprehensive interpretation is that genetic improvement in sycamore vigor will be achieved only when knowledge of site adaptability is increased (survival does not appear to be a factor (Briscoe 1969; McAlpine 1963)).

This conclusion may seem obvious, but the answers to the questions, "What constitutes site adaptability in terms of genes, growth, and the environmental factors which affect them?" and "How do we predict adaptability?" are not at all obvious at the present time.

LITERATURE CITED

Briscoe, C. B. 1969. Establishment and early care of sycamore plantations. USDA Forest Serv. Res. Pap. SO-50, 18 p. South. Forest Exp. Stn., New Orleans, La.

Fogg, P. J. 1966. Second-year results from a geographic seed-source test of planted American sycamore. La. State Univ., Sch. of For., LSU For. Note 66, 2 p.

Kaszkurewicz, A., and Fogg, P. J. 1967. Growing seasons of cottonwood and sycamore as related to geographic and environmental factors. Ecology 48: 785-793.

McAlpine, R. G. 1963. A comparison of growth and survival between sycamore seedlings and cuttings. USDA Forest Serv. Res. Note SE-9, 1 p. Southeast. Forest Exp. Stn., Asheville, N. C.

Mosteller, F., and Youtz, C. 1961. Tables of Freeman-Tukey transformations for the binomial and Poisson distributions. Biometrika 48: 433-440.

Schmitt, D. M., and Webb, C. 1970. The relation of forest genetics research to southern hardwood tree improvement programs. In Silviculture and Management of Southern Hardwoods, p. 89-100. La. State Univ. 19th Annu. For Symp. Proc. 1970, La. State Univ. Press.

Steinbeck, K. 1971. Growth responses of clonal lines of American sycamore grown under different intensities of nutrition. Can. J. Bot. 49: 353-358.

U. S. Department of Agriculture. 1941. Climate and man. Yearb. of Agric. U. S. Gov. Print. Off., Wash., D. C. 1248 p.

USDA Forest Service. 1965. Silvics of forest trees of the United States. (Compiled by H. A. Fowells.) USDA Agric. Handb. 271. 762 p.

Webb, C. D. 1970. Early results of performance trials of American sycamore. Abstracts, First North Am. Forest Biol. Workshop. Mich. State Univ., East Lansing, Mich. August 5-7, 1970.

Webb, C. D., and Farmer, R. E., Jr. 1968. Sycamore seed germination: the effects of provenance, stratification, temperature, and parent trees. USDA Forest Serv. Res. Note SE-100, 6 p. Southeast. Forest Exp. Stn., Asheville, N. C.

VARIATIONS IN GROWTH AND FORM IN YOUNG PLANTATION BLACK WALNUT TREES

Calvin F. Bey,[1] Norman L. Hawker,[2] and Paul L. Roth[3]

Action programs and research for genetic improvement of black walnut (Juglans nigra L.) have been started in many areas in the Eastern United States. As new information becomes available, additional walnut improvement programs will undoubtedly be started.

We believe that improvement programs should be aimed primarily at producing straight, rapid growing trees. In plantations there is little, if any, problem in selecting the largest trees, but selecting for stem straightness is more difficult. Since straightness, branching habit, and apical dominance are generally considered interrelated, we decided to examine the intercorrelations among these and other characters. We have conducted a preliminary plantation survey and established a progeny test.

In the plantation survey we found: (1) No correlation exists between the number of branches on 1-year-old wood 1 year and 1-year-old wood the next. (2) Number of branches developing on 1-year-old wood was not significantly correlated with the amount of current year's terminal growth. (3) A negative correlation was found between branch angle of branches on 1-year-old wood of succeeding years. (4) Branch angle measured from the zenith increases as branches become older.

PROGENY TESTING

Method

In an attempt to evaluate the genetic aspect of growth and form in walnut, we started a study in 1966 using seed from 17 parent trees from six widely separated geographic sources (table 1). The field planting consists of 308 trees in a completely randomized hierarchal design. The 308 trees were derived from 154 nuts. Genetically identical pairs were derived by longitudinally splitting the hypocotyl and epicotyl of germinating seeds (Bey, 1967) (fig. 1). Each seedling was grown in a pot for 1 year, transplanted into the nursery for 1 year, and then transplanted to the field in 1968. The

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[1] Plant Geneticist, North Central Forest Experiment Station, Carbondale, Illinois (office maintained in cooperation with Southern Illinois University).

[2] Graduate Student in the Department of Forestry, Southern Illinois University, Carbondale, Illinois.

[3] Assistant Professor, Department of Forestry, Southern Illinois University, Carbondale, Illinois.

Table 1.--Location and average value by family and source for eleven characters

Source Location	Family no.	Height 1970	Diameter 1970	Length of branches below current year's terminal 1969	Length of branches below current year's terminal 1970	No. branches below current year's terminal 1970	No. lateral buds on current year's terminal 1969	No. lateral buds on current year's terminal 1970	Leaf flush-days after April 1, 1970	Leaf fall-days after Aug. 1, 1970	Index of crook 1969	Index of crook 1970
		cm	mm	cm	cm							
Winona Co.,	102	102.2	21.2	8.5	71.2	3.2	26.0	21.8	22.7	43.5	11.8	13.1
Minnesota	103	107.5	21.9	17.4	140.4	4.4	21.8	18.5	25.7	34.7	4.9	20.2
	108	97.4	18.7	7.0	94.2	3.5	20.5	18.7	29.4	36.5	10.5	18.4
Source 1 ave.		101.9	20.2	11.3	111.4	3.8	21.4	18.8	27.4	36.3	8.3	17.2
Delaware Co.,	206	97.2	20.7	2.5	43.1	2.7	21.7	21.2	24.3	33.5	3.8	15.6
Iowa	210	100.0	20.1	17.4	157.2	4.1	21.6	17.3	31.6	31.8	5.1	21.5
	212	107.1	21.6	17.8	212.0	7.4	22.4	20.3	26.8	44.6	7.1	12.4
Source 2 ave.		103.5	21.0	15.4	170.2	5.7	22.1	19.5	27.9	39.1	6.0	16.5
Marion Co.,	302	147.0	26.3	67.3	309.7	10.7	32.2	22.3	26.0	36.3	8.7	14.2
Missouri	305	123.9	26.5	37.8	294.9	7.4	28.5	21.3	29.7	47.8	10.5	18.1
	310	113.8	21.6	7.6	80.6	1.8	25.4	24.0	29.7	47.1	3.9	9.0
Source 3 ave.		125.8	25.1	35.7	240.7	6.5	28.4	22.2	29.0	45.3	8.4	13.8
Dent Co.,	401	132.4	26.5	62.4	248.5	7.4	31.8	23.3	30.6	50.1	13.3	18.0
Missouri	407	135.7	26.2	32.4	269.8	7.9	31.1	22.3	27.2	49.6	10.9	23.5
	410	128.0	24.6	17.6	157.7	5.3	29.4	26.9	28.2	53.4	9.8	14.9
Source 4 ave.		131.5	25.7	38.1	217.9	6.7	30.7	24.5	28.9	51.3	11.4	18.8
Stone Co.,	502	152.9	27.4	40.4	298.9	7.2	35.3	25.7	24.8	54.1	14.5	16.9
Arkansas	504	136.8	26.7	49.7	233.0	4.9	30.3	24.4	22.2	56.1	16.4	21.0
	506	142.0	28.2	41.7	292.8	6.6	31.6	24.0	24.0	55.8	21.1	26.7
Source 5 ave.		143.9	27.4	43.9	275.2	6.2	32.4	24.7	23.7	55.3	17.4	21.5
Walker Co.,	602	156.2	30.7	86.0	401.3	7.9	41.9	25.9	19.5	74.1	28.1	30.3
Texas	604	150.8	33.3	71.0	452.8	8.0	32.0	24.0	19.0	82.1	28.2	30.8
Source 6 ave.		154.2	31.7	81.7	420.6	7.9	39.1	25.2	19.4	77.1	28.1	30.5

seedlings were smaller than most 1-year-old transplant stock. The field was sprayed with simazine (2.5 lb./acre) and atrazine (2.5 lb./acre) each year to control weeds. The trees were "correctively pruned" (lateral branches removed that were competing with the terminal for a dominant position) during the growing season of the first two years--1968 and 1969.

At the end of the 1968 and 1969 growing seasons, as well as during and after the 1970 growing season, we made a detailed study of the following growth and form characters.

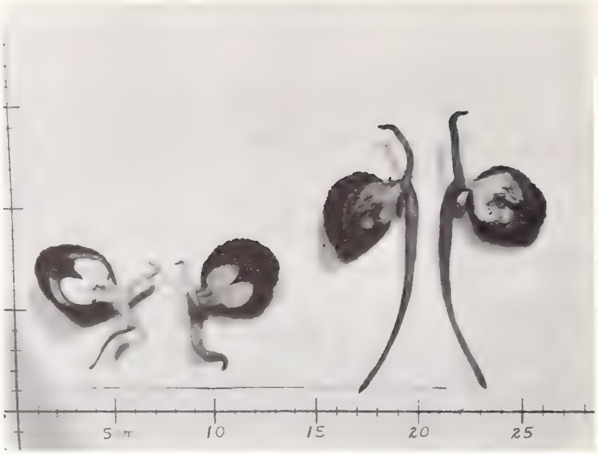

Figure 1.--Genetically identical pairs were derived by splitting germinating seeds.

1. Diameter at 15 cm above ground and total height were measured to the nearest millimeter and centimeter, respectively.
2. Length of branches below current year's terminal was measured to the nearest cm in 1969 and 1970.
3. The number of branches below the current year's terminal were counted in 1970.
4. The number of lateral buds on current year's terminal were counted in 1969 and 1970.
5. Flushing was considered to have occurred when the first leaf reached 2.5 cm in length.
6. Leaf fall was considered to have occurred when all the leaflets had fallen from all the leaves or all but one.
7. Index of crook was computed as the sum of (1) degrees lean, (2) number of crooks x 10/total height, and (3) degree of maximum crook.

"Lean" was measured from the base of the tree to the tip. Any deviation of 2.5 cm or more from bole to a straight line tangent to the bole was considered a "crook". "Maximum crook" is the value for the distance from bole to a straight line tangent to the crook in the bole x 100 divided by the length of the straight line. "Maximum crook" values were then adjusted so that on the average they contributed the same as the component for number of crooks. For 1969 and 1970, lean contributed 30 and 27 percent, respectively, to the total index of crook values.

Results

Analysis of variance revealed that after 5 years trees from southern sources were generally taller and larger in diameter, had greater branch length after 1969, developed more lateral buds on the current year's terminal, flushed earlier, and dropped their leaves later than trees from local and northern sources (table 2). Although ANOVA revealed no significant differences between sources for (1) number of branches below current year's terminal, (2) total branch length after 1970, (3) index of crook 1969, and (4) index of crook 1970, these characters are correlated with height. Using source means, the correlations (r) between height and variables (1)-(4) are .92, .84, .88, and .75, respectively. These correlation coefficients are significant at the .05 level. This would indicate that selection for fast growing sources will mean concurrent selection for trees that have more branches and more crook.

Table 2.--Mean squares for eleven characters by sources, families, pairs, and error

	Height	Diameter	Length of branches below current year's terminal		No. branches below current year's terminal	No. lateral buds on current year's terminal		Leaf flush-days after	Leaf fall-days after	Index of crook	
	1970	1970	1969	1970	1970	1969	1970	April 1, 1970	Aug. 1, 1970	1969	1970
Sources	20,379**	671**	15,097*	152,494	78	1,614**	425**	518**	6,157**	1,189	755
Families/S	996	32	4,273	59,050	55	106	74*	74**	331*	497**	325
Pairs/F	1,497	57	2,785	88,480**	33**	82**	39**	18**	171**	177*	203**
Individuals/P (error)	858	36	2,373	7,542	19	45	25	9	58	124	317

** Indicates significant difference at .01 probability level.
* Indicates significant difference at .05 probability level.

The hierarchal design also permitted us to test for differences among families within sources, and among pairs within families (table 2). There were differences among families within sources for number of lateral buds on current year's terminal in 1970, leaf flush, leaf fall, and index of crook for 1969. There were differences among pairs within families for all characters except height, diameter, and length of branches below current year's terminal in 1969. The fact that few characters show differences among families suggests that trees within stands are related--perhaps coming from a common parent several generations in the past.

The phenotypic and genetic contribution due to sources, families, and pairs was computed using the following model:

	D.f.	EMS
Sources	5	$\sigma_e^2 + 2\sigma_P^2 + 18.65\sigma_F^2 + 48.23\sigma_S^2$
Families in sources	11	$\sigma_e^2 + 2\sigma_P^2 + 17.32\sigma_F^2$
Pairs in families	137	$\sigma_e^2 + 2\sigma_P^2$
Error--within pairs	154	σ_e^2

The variance coefficients were adjusted because of an unbalanced design (Sokal and Rohlf, 1969). The phenotypic variance for error was generally high (table 3). The higher the error variance, the greater the opportunity for improvement through silvicultural manipulation. Conversely, relatively low error variances, as for leaf flush and leaf fall, indicate that there is a better chance for gain through genetic manipulation.

Table 3.--Phenotypic variance due to sources, families, pairs, and error (expressed as percent of total variance)

	Height	Diameter	Length of branches below current year's terminal		No. branches below current year's terminal	No. lateral buds on current year's terminal		Leaf flush--days after	Leaf fall--days after	Index of crook	
	1970	1970	1969	1970	1970	1969	1970	April 1, 1970	Aug. 1, 1970	1969	1970
Sources	25	22	8	3	1	29	18	36	49	8	5
Families/S	0	0	3	0	5	2	5	13	4	10	7
Pairs/F	20	18	7	82	29	20	16	18	23	14	64
Individuals/P (error)	55	60	82	15	68	49	61	33	24	68	24

In general, the family component for genetic variance was very low, while source and pair components were high (table 4). High source components, as for the growth characters, indicate large genetic differences among stands. Low family components indicate minor genetic differences within stands. High pair components indicate large genetic differences within progeny from individual trees.

Heritability for each character was computed as the ratio of total genetic variance over total phenotypic variance (table 4). The heritability values were .40 or higher for 7 of the 11 characters. The potential for genetic gain through selection for growth, flushing, and leaf fall appear good.

Table 4.--Genetic variance due to sources, families, and pairs (expressed as percent of total genetic variance) and heritability values*

	Height	Diameter	Length of branches below current year's terminal		No. branches below current year's terminal	No. lateral buds on current year's terminal		Leaf flush-days after	Leaf fall-days after	Index of crook	
	1970	1970	1969	1970	1970	1969	1970	April 1, 1970	Aug. 1, 1970	1969	1970
Source	55	54	43	3	4	57	45	54	65	24	7
Families	0	0	17	0	15	3	13	19	5	31	9
Pairs	45	46	40	97	81	40	42	27	30	45	84
Heritability	.45	.40	.18	.85	.32	.51	.39	.67	.76	.32	.76

*Expressed as ratio of total genetic variance over total phenotypic variance.

Implications

For any specified planting zone (e.g., a state, part of a state, etc.), it is important to first define the geographic area whose seed gives the "best" performance. This study and other early tests indicate that for southern Illinois plantings, south-of-local areas are "best" for growth characters (Bey, Toliver, and Roth, 1971).

Within the "best" seed collection areas collect seed from few trees per stand but many stands. For characters such as height and diameter having low family variance, many parent trees will need to be included for family selection to be effective. Where family variance is relatively high, such as for leaf flush, family selection would be effective with fewer parent trees.

In roguing progeny tests (for the purpose of converting to seedling seed orchards), it appears that we should save some trees from most of the families. For example, if we use 12 families (those with 10 or more trees per family) from the data presented here, and select all trees taller than 162 cm (the best 20 percent of all trees), we would select some trees from all except one family (table 5).

One alternative to the minimum selection approach is to make use of the family means and variances. Normal probability paper is useful when using this procedure (Kung and Squillace, 1971) (fig. 2). When the cumulative curve of a normal distribution is plotted on normal probability paper, it becomes a straight line. The mean appears on the 50th percentile and one standard deviation above the mean will be on the 84.13 percentile. Using this procedure, and again selecting 20 percent of all trees, we would select some

Table 5.--A comparison of methods for making selections

Family number	Mean ht.	Percent of trees selected in each family	
		Minimum selection-- 162+ cm in height	Selection based on family means and standard deviations
	Cm	Percent	Percent
103	107.5	4	3
108	97.4	4	3
210	100.0	-	2
212	107.1	9	6
305	124.0	19	15
401	132.4	42	24
407	135.7	19	22
410	128.0	12	19
502	152.9	47	44
504	136.8	21	25
506	142.1	22	31
602	156.2	40	44

trees from all families. The percentages selected within each family by the two methods are in close agreement. In cases where phenotypic variances are proportional to genetic variances, the selection method based on means and variances makes greater use of the data and may lead to greater improvement.

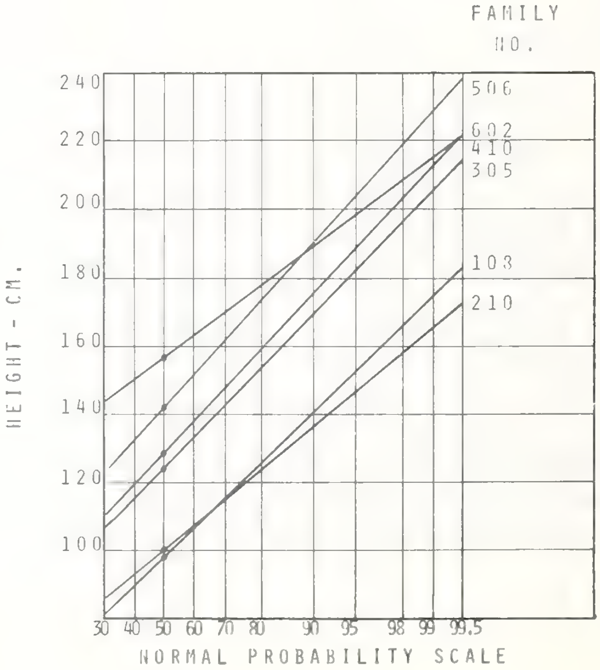

Figure 2.--Estimated cumulative frequency distribution for height of tree. One family from each source is shown.

LITERATURE CITED

Bey, C. F. 1967. Obtaining genetically identical black walnut seedlings. Ill. Quality Nut Tree 6(1):5-8, illus.

Bey, C. F., Toliver, J. R. and Roth, P. L. 1971. Early growth of black walnut trees from twenty seed sources. U.S. Forest Serv. Res. Note NC-105, 4 pp.

Kung, F. H. and Squillace, A. E. 1971. Use of population variance in selection for forest tree improvement. Paper presented to the Working Group on Quantitative Genetics of Sec. 22, IUFRO, March 14-20, 1971, Gainesville, Fla.

Sokal, R. R. and Rohlf, F. J. 1969. Biometry--the principles and practice of statistics in biological research. W. H. Freeman and Co., San Francisco. 776 pp.

Variation in Monoterpene Composition of Loblolly Pine as Related to Geographic Source of Seed[1]

A. R. Gilmore
University of Illinois at Urbana-Champaign[2]

A number of studies have shown local and/or regional variation in the monoterpenes of some coniferous species. One of the most comprehensive studies was conducted by Smith _et al_. (1969) on ponderosa pine. Based on terpene analyses, they found evidence to support the establishment of at least four major and four minor regional types of ponderosa pine. No study of this nature has been reported for the southern pines. There are many reasons why this is true, one being the scarcity of suitable plant material growing in an area where differences in environment are relegated to a minimum.

A 21-year-old plantation in southern Illinois provided an opportunity to study the relationship between monoterpenes and geographic races of loblolly pine (_Pinus taeda_ L.) growing in a uniform area but outside its natural range. The most northerly range of loblolly pine in the Mississippi River Valley is in northern Mississippi and western Tennessee, which is about 200 miles south of the plantation used in this study.

Methods

Seed from six geographic sources of loblolly pine were obtained from trees growing in the following areas and planted during the 1948 season in the Union State Nursery near Jonesboro, Illinois: (1) southwestern Arkansas (Ark.); (2) throughout Mississippi (Miss.); (3) throughout South Carolina (S.Car.); (4) Pender County, North Carolina (N.Car.); (5) Matthews County, Virginia (Va.); and (6) Worcester County, Maryland (Md.).

Planting stock was graded to eliminate culls, according to the quality standards used in the Jonesboro nursery at that time, and 1-0 seedlings were planted at 6- x 6-foot spacing in two blocks of a randomized block design. The plantation is located in the "claypan" area of southern Illinois about 4 miles west of West Frankfort. The soil type is a Wynoose silt loam (Typic Albaqual) and is relatively uniform over the planted area. Growth measurements were taken by staff members of the Carbondale Research Center, U. S. Forest Service, at the end of the tenth growing season. At this time mean tree height ranged from 19.3 feet to 22.3 feet for the six seed sources, and survival percentages ranged from 81.0 percent to 95.3 percent.

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[1] Plantation established by L. S. Minckler (retired) while he was a member of the staff at Carbondale Research Center. The plantation is a part of the "Plan for Pine Seed Source and Pine Hybrid Studies in Southern Illinois," dated September 15, 1948. The author expresses his gratitude to the North Central Forest Experiment Station, U.S.D.A., for permitting him to use material from the plantation in this study.

[2] A portion of this research was supported by funds from the Illinois Agricultural Experiment Station, McIntire-Stennis Project 55-360.

At the end of 21 growing seasons, one tree in each of the 8 interior rows in a plot was randomly selected for oleoresin analysis. Thus oleoresin samples were collected from 16 trees in each seed source. A V-notch was cut at breast height on the north side of each tree that extended through the bark to the xylem. Oleoresin oozing from each cut was placed in a small vial, and the air in the vial was replaced with nitrogen. The vials were placed on dry ice shortly after collection, and the oleoresin was kept frozen until it was used for terpene analysis.

Terpene analysis was determined with a Hewlett-Packard Model 5750 Gas Chromatograph. Oleoresin was dissolved in pentane, and the analysis was performed using a stainless steel column packed with 20 percent Carbowax 20M liquid phase on 60-80 mesh, acid-washed Chromosorb W solid support. In addition, peak separation was checked on another column using 5 percent B, B'-oxidipropionitrile in place of the Carbowax 20M. This check revealed that no peaks were produced that were not observed when the original column was used.

Concentration of each terpene is expressed as a percentage of the total terpene concentration.

Results

Five terpenes were found in the oleoresin of all seed sources. The order in which they eluted from the Gas Chromatograph column were alpha-pinene, camphene, beta-pinene, myrcene, and limonene. The average composition according to seed source is shown in Table 1.

Table 1. Average monoterpene composition according to geographic source of seed.

Monoterpene	Miss.	Ark.	S.Car.	N.Car.	Va.	Md.
			Percent			
Alpha-pinene[a]	71.59	73.22	76.48	79.94	81.55	83.54
Camphene[b]	1.04	1.27	1.04	1.46	1.37	0.80
Beta-pinene[c]	20.29	17.45	16.29	10.24	11.00	10.84
Myrcene[d]	3.77	4.59	4.55	6.13	4.33	3.57
Limonene[e]	3.31	3.47	1.64	2.23	1.73	1.25

[a] Miss. different from N.Car., Va., and Md. at 1 percent level. Ark. different from Va. and Md. at 1 percent level and from N.Car. at 5 percent level.

[b] Md. different from Va. and N.Car. at 1 percent level and from Ark. at 5 percent level. N.Car. different from S.Car. and Miss. at 5 percent level.

[c] Miss. different from N.Car., Va., and Md. at 1 percent level. N.Car. different from S.Car. and Ark., and Ark. different from Va. and Md. at 5 percent level.

[d] N.Car. different from all other sources at 1 percent level.

[e] Miss. different from Va. and Md. at 1 percent level and from S.Car. and N.Car. at 5 percent level. Ark. different from S.Car., Va., and Md. at 1 percent level and from N.Car. at 5 percent level.

Alpha-pinene averaged 71.59 percent in the most southerly seed source and increased almost linearly to the Maryland source, which averaged 83.54 percent. The concentration of camphene appeared to be greatest near the midpoint of the species natural range, decreasing to a low level at the extreme of its range. Beta-pinene was greatest in the southerly sources and the least concentrated in the northerly sources. Myrcene was similar to camphene in that the concentration was greatest near the midpoint of the species range and least at the extremes of the range. Limonene followed the general pattern of beta-pinene in that its concentration was greatest in trees grown from seed obtained from southern sources and least in the northern sources.

There was considerable tree-to-tree variation in the composition of the terpene fractions not only for all trees (Table 2) but also for trees within a seed source.

Table 2. Ranges in terpene concentration for all trees.

Terpene	Range (percent)
Alpha-pinene	56.56 - 95.51
Camphene	0.03 - 2.21
Beta-pinene	1.13 - 37.30
Myrcene	1.53 - 9.29
Limonene	0.26 - 6.84

There was no difference in terpene composition by blocks. The total height of the plantation was relatively uniform and averaged about 50 feet. The diameter at breast height (dbh) of the study trees ranged from 4.1 to 10.1 inches with the mean 6.5 inches. No correlation was found between either terpene concentrations and dbh or total height.

Discussion

When compared with other studies, terpenes in this study show similarities as well as differences. For example, Smith *et al.* (1969) found five major terpenes in ponderosa pine oleoresin, four of them the same as those found in loblolly pine. They reported only a trace of camphene in ponderosa but found large amounts of 3-carene. Lotan and Joye (1970) reported that lodgepole pine contained the five terpenes found in loblolly, plus four others. In slash pine, Roberts (1970) found two additional terpenes beside the five reported for loblolly. These differences demonstrate that terpenes differ widely in *Pinus* species, even in the closely related species such as yellow pines.

Environment had little effect on terpene concentration in the study, as the trees are growing on a relatively uniform area. Therefore, differences in terpene concentrations must be related to genetics, even though tree-to-tree variations in terpene levels are large.

An interesting aspect of the study is to speculate on the relationship of monoterpenes to plant-insect interactions. Since beetles react differently to terpene variation, a paramount consideration is the behavior of beetles to resin vapor prior to tissue invasion. The volatile fraction of oleoresin, the terpenes, apparently plays a dual role in pine-beetle relationships. Vapors of individual terpenes have the ability either to attract beetles to the source tree (Chapman, 1963), or to repel or kill the insect. Smith (1965) has demonstrated the variable toxicity of pine resin vapor to several species of *Dendroctonus* bark beetles. He noted that vapor concentration seems to be the factor determining whether the terpenes will be attractants or deterrents. Also, Chararas (1958) found that in high concentrations the terpenes, alpha-pinene, beta-pinene, and terpineol were all repellent to bark beetles, but attractants in low concentration. Concentration may not be the only factor that determines the toxicity or attractiveness of the terpenes. Olfactometer tests with Douglas-fir beetles (Heikkenen and Hrufiord, 1965) indicated that alpha-pinene is an attractant, whereas beta-pinene may repel the beetles. They hypothesized that when the ratio of alpha-pinene to beta-pinene is low, the beetles are repelled; this is the normal situation, but, according to their hypothesis, the ratio can be upset when low soil moisture produces a reduction in the cooling properties of evapotranspiration; then the heating effect of radiant energy might cause volatilization of alpha-pinene, resulting in beetle attraction.

The author is unaware of any study pertaining to the susceptibility of these geographic races of loblolly pine to insect attack. Nevertheless, terpene composition has been shown to be an inherited factor in a number of coniferous species and that terpenes might play a part in attracting or repelling insects to a particular host. For example, Smith *et al*. (1969) found distinct patterns of monoterpene composition in geographic races of ponderosa pine. They noted that the western pine beetle is not found in the region occupied by ponderosa pine of var. *scopulorum* and that trees in this region have a high concentration of 3-carene. Also, the beetle is not found in regions occupied by var. *arizonica*, where alpha-pinene is high. In general, they noted that this beetle was not normally found in areas of ponderosa pine where a monoterpene occurred as a large percentage of the terpene composition.

Many clues of host-insect attractants need to be investigated, and hopefully this mystery will become clear in the not too distant future.

Literature Cited

1. Callaham, R. Z. 1966. Nature of resistance of pines to bark beetles. pp. 197-201. In breeding pest-resistant trees. Pergamon Press, Oxford.

2. Chapman, J. A. 1963. Field selection of different log odors by Scolytid beetles. Canad. Ent. 95: 673-676.

3. Chararas, C. 1958. The attraction of some constituents of oleoresins to Scolytidae attacking conifer. C. R. Acad. Sci., Paris. 24: 1653-1654. (Abstr.)

4. Heikkenen, H. K., and B. F. Hrutfiord. 1965. *Dendroctonus pseudotsuga* a hypothesis regarding its primary attractant. Sci. 150 (3702): 1457-1459.

5. Lotan, J. E., and N. M. Joye, Jr. 1970. Some variation of terpenes in Montana lodgepole pine. Intermountain Forest and Range Exp. Sta. U. S. Forest Serv. Res. Note INT-120, 4 pp.

6. Roberts, D. R. 1970. Within-tree variation of monoterpene hydrocarbon composition of slash pine oleoresin. Phytochem. 9: 809-815.

7. Smith, R. H. 1965. Effect of monoterpene vapors on the western pine beetle. J. Econ. Ent. 58: 509-510.

8. Smith, R. H., R. L. Peloquin, and P. C. Passoff. 1969. Local and regional variation in the monoterpenes of ponderosa pine wood oleoresin. Pacific S. W. Forest and Range Exp. Sta. U. S. Forest Serv. Res. Paper PSW-56, 10 pp.

ESTIMATES OF HERITABILITIES AND GENETIC GAINS FOR POPULATIONS OF VIRGINIA PINE[1]

Richard M. Evans[2] and Eyvind Thor[3]

In 1962, the Kentucky-Tennessee Section of the Society of American Foresters sponsored a study to determine the natural variation in Virginia pine (Pinus virginiana Mill.). There were two main objectives in the proposed study: to determine the natural variation in wood properties and to determine the genetic variation in open-pollinated progenies in the natural populations of Virginia pine found in Kentucky and Tennessee. Thor (1964) has reported information relating to the first objective. This paper presents some results of studies concerned with the second objective.

METHODS

In September and October of 1963, 1964, and 1965 open-pollinated seed were collected from 7 to 13 parent trees in 12 natural stands in Kentucky and Tennessee. The stands were located in seven physiographic regions and were considered to be representative of the natural populations (Figure 1). Only even-aged stands of average or better than average quality were used. Parent trees were healthy dominants or codominants with poor, average or excellent phenotypic characteristics. Stands varied in age from 28 to 58 years old and were on site indexes from 60 to 87 feet (Table 1).

One-year-old seedlings, grown in unreplicated family plots at the Tennessee Valley Authority's nursery at Norris, Tennessee were lifted for planting in the spring of 1967. From 57 to 127 families were planted in 10-tree-row family plots at a 5 by 8 foot spacing in 6 test locations. A randomized complete block design was used with 9 or 10 replication at each test site.

Test sites were widely scattered with 80 or more miles between each site (Figure 1). Two sites, Ames Plantation and Vina, were in the Coastal Plain geographical region of western Tennessee and northwestern Alabama, respectively. The Highland

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[1] This work is based on the senior author's MS Thesis at The University of Tennessee.

[2] Formerly, Graduate Research Assistant, The University of Tennessee. Presently, Assistant Geneticist, Western Gulf Forest Tree Improvement Program, College Station, Texas.

[3] Associate Professor of Forestry, The University of Tennessee, Knoxville, Tennessee.

Table 1. Location of sample plots, site indexes, and average values for D.B.H. and age. Averages are based on 15 trees per stand

Stand No.	Physiographic Region	Location	Co-operator	Site Index (ft. at 50 yrs)	D.B.H. (inches)	Total Age (years)
1	West Tennessee	Clifton, Tenn.	Univ. of Tenn.	75	9.0	28
2	West Kentucky	Dawson Springs, Kentucky	Ky. State Div. Forestry	69	11.6	52
3	Cumberland Plateau	Sewanee, Tenn.	USFS, Sewanee	73	9.7	34
4	Eastern Highland Rim	Rock Island, Tenn.	Univ. of Tenn.	74	10.2	42
6	Cumberland Mountains	Wartburg, Tenn.	Univ. of Tenn.	87	8.9	35
7	Eastern Ridge	Pineville, Ky.	Ky. State Div. Forestry	82	9.5	42
8	Cumberland Plateau	London, Ky.	USFS, Berea	83	10.9	47
9	Cumberland Plateau	Morehead, Ky.	Cumberland National Forest	69	8.8	32
10	Great Valley	Etowah, Tenn.	Cherokee National Forest	81	9.0	34
11	Great Valley	Vonore, Tenn.	Hiwasse Land Co.	60	9.8	53
12	Great Valley	Newport, Tenn.	Univ. of Tenn.	75	9.7	42
13	Great Valley	Elizabethton, Tenn.	Cherokee National Forest	64	11.1	43

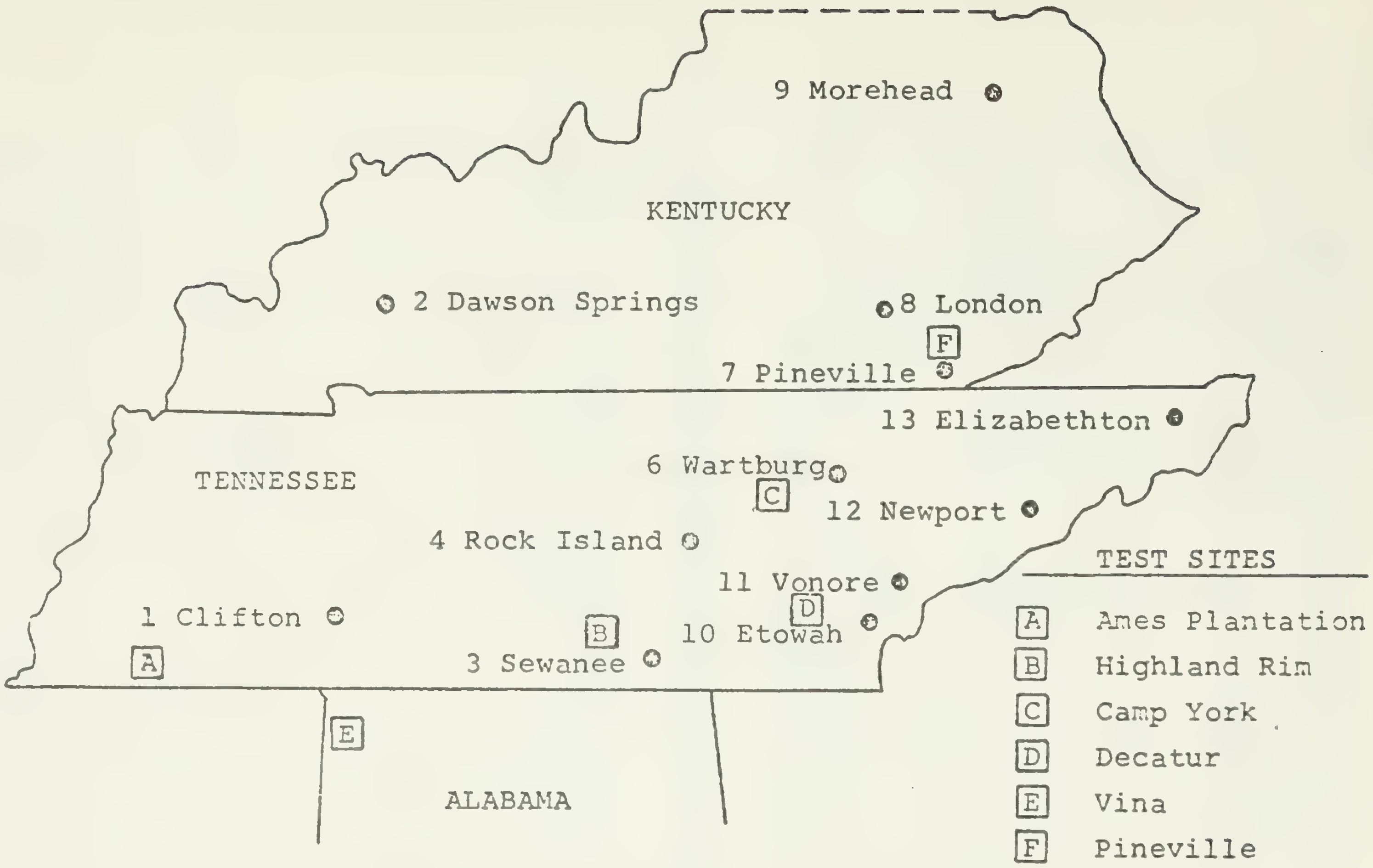

Figure 1. Locations of stands and test sites.

Rim site was located in the eastern highland rim of central Tennessee and had the most homogeneous site conditions of all test locations. The Camp York and Decatur sites were located on the Cumberland Plateau and the Ridge and Valley regions of eastern Tennessee, respectively. The Pineville test site, the most northern site, was located in eastern Kentucky on strip mine spoil.

Field measurements were made at the end of the 1967 and 1968 growing seasons. The seedlings at that time were two- and three-years old, respectively. In 1967, one growing season after planting, seedling height was measured. In 1968, after the second growing season, seedling height, stem diameter, branch length, and branch diameter were measured. Altogether about 52,000 trees were measured.

An analysis of variance was performed on an individual tree basis for each characteristic measured at each location. Effects due to stands, replications, families within stands, and trees within plots were assumed to be random. All analyses were calculated on an IBM 360 Model 65.

Components of variance and heritabilities calculated on an individual tree basis were estimated from the mean square components:

Source of variation	Expected components
Families in stands	$\sigma_w^2 + w\sigma^2_{f(s)r} + wr\sigma^2_{f(s)}$
Families in stands x replications	$\sigma_w^2 + w\sigma^2_{f(s)r}$
Within plot	σ_w^2
Heritability	$h^2 = \dfrac{4\,\sigma^2_{f(s)}}{\sigma_w^2 + \sigma^2_{f(s)r} + \sigma^2_{f(s)}}$

RESULTS AND DISCUSSIONS

Mean Values. All families were not represented at every test site. Therefore, differences in mean values among sites must partially be contributed to families not common among compared test sites and are not a valid indication of environmental differences. To facilitate a comparison of means among test sites, mean stand values of second-year height for families common to all test sites are summarized in Table 2. The Highland Rim site (B) has the overall

Table 2. Second-year mean stand height for families common to all test sites

Stand	Test Sites A	B	C	D	E	F
2	2.36	3.19	1.82	2.47	3.18	1.24
3	2.32	3.33	1.95	2.34	3.13	1.37
4	2.40	3.48	2.21	2.78	3.31	1.28
6	2.36	3.36	1.94	2.74	3.13	1.29
7	2.38	3.41	2.04	2.72	3.22	1.47
8	2.41	3.26	1.93	2.56	3.16	1.25
9	2.39	3.47	2.20	3.18	3.22	1.34
10	2.61	3.64	2.23	2.86	3.51	1.40
11	2.51	3.47	2.04	2.80	3.42	1.56
13	2.54	3.56	2.00	2.85	3.45	1.34
Average	2.42	3.42	2.04	2.73	3.27	1.35

Table 3. Ranking of stands within each test site based on second-year mean height[a]

Ranking	Test Sites A	B	C	D	E	F
1	10	10	10	9	10	11
2	11	13	4	10	13	7
3	13	4	9	13	11	10
4	8	9	7	11	4	3
5	4	11	11	4	7	9
6	9	7	13	6	8	13
7	7	6	3	7	2	6
8	2	3	6	8	8	4
9	6	8	8	2	3	8
10	3	2	2	3	6	2

[a] Stands ranked in descending order by stand mean heights presented in Table 2.

largest second-year mean height (3.42 feet) and each stand mean value is larger than that observed for any other test site. Likewise, the smallest test site mean height (1.35 feet) was found at Pineville (F); consistently this strip mine site had the smallest mean stand heights.

Table 3 presents a ranking at each test site of the mean second-year stand heights. Some stands tend consistently to be ranked relatively high or low. For example, Stand 10 is ranked among the best three at all test sites, and Stand 2 is consistently ranked lower than seventh. Furthermore, common among the stands ranked relatively high or low is a tendency for them to be from the same physiographic region. Stands 10, 11, and 13 of the Great Valley physiographic source (Table 1) rank in the upper 30 percent 13 times out of the possible 18 (72 percent). If the stands of this physiographic source were ranked randomly one would expect only 5 out of the possible 18 in the upper 30 percent of all stands. A chi-square test indicated that the ranking of physiographic sources was different from the results of random distribution. The F-test indicates significant difference in second-year height among stands at all test sites.

Components of variance and heritabilities. Estimates of variance components and heritabilities are presented in Table 4 for second-year height and second-year stem diameter. Since all families were not represented at all locations, differences in variances among test sites are partially attributed to variances among uncommon families. However, general comparisons will be made on the assumption that variances and means of uncommon families are the same as among common families.

In comparing the variances of Table 4 to the means of Table 2 the effects of scale (Falconer, 1967) are apparent. For example, Highland Rim which has the largest mean second-year height also has the larger variances. In contrast, the Pineville site has the smallest mean height and variances.

The standard errors of the family within-stand variance, as calculated by Snyder (1969), were in general small. Average standard errors were 20 to 25 percent of the family within-stand variance.

Heritability estimates were highly variable among test sites. Estimates for first-year heights range between the Highland Rim (h^2=0.44) and Ames Plantation (0.17) test sites. Estimates of second year height heritability ranged from 0.48 to 0.17 at the Highland Rim and Ames sites, respectively.

Estimates of genetic gains. Estimates of phenotypic and genetic variance are of little practical value by themselves. The ultimate use of the estimates is to predict the amount of improvement, i.e., genetic gain, possible for a particular breeding program.

Table 4. Estimates of components of variance, standard error of family within-stand variance, and heritability for second-year seedling height and stem diameter

	o^2_w	$o^2_{f(s)r}$	$o^2_{f(s)}$	$s\left[o^2_{f(s)}\right]^a$	h^2
Height					
Ames	33.52[b]	6.01	1.66	0.41	0.16
Highland Rim	43.02	4.66	6.58	0.99	0.48
Camp York	43.63	6.26	3.78	0.89	0.28
Decatur	47.72	8.82	3.29	0.79	0.22
Vina	43.64	7.46	4.70	0.97	0.34
Pineville	17.16	3.67	1.28	0.41	0.23
Diameter					
Ames	0.777[b]	0.136	0.018	0.006	0.08
Highland Rim	0.961	0.088	0.119	0.017	0.41
Camp York	1.016	0.142	0.066	0.015	0.21
Decatur	0.874	0.186	0.044	0.013	0.16
Vina	1.310	0.157	0.076	0.018	0.20
Pineville	2.111	0.561	0.108	0.042	0.16

[a] $s\left[o^2_{f(s)}\right]$ = Standard error of family within stand variance.

[b] Components of variances are presented as $o^2 \times 10^{+2}$.

Genetic gains for selection of the best stands and the best families and individuals within families was calculated for second-year heights at the Highland Rim. It was assumed that no genetic gain was made in the initial selection of parent trees. The formula used for predicting the genetic gain (G), for family and within family selection is represented as:

$$G = i_1 \frac{\sigma^2_{f(s)}}{\sigma_1} + i_2 \frac{3\,\sigma^2_{f(s)}}{\sigma_2}$$ (Namkoong, *et*.*al*., 1965)

Where:

i_1 = family selection intensity

i_2 = within family selection intensity

$$\sigma_1^2 = \frac{\sigma_w^2}{nr} + \frac{\sigma^2_{f(s)r}}{r} + \sigma^2_{f(s)}$$

$$\sigma_2^2 = \sigma_w^2 + \sigma^2_{f(s)r}$$

Genetic gains were calculated for two selection schemes. The two schemes differ only in that in Scheme I the tallest families were chosen from families of all stands, while in Scheme II the tallest families were chosen from families of the seven stands with greatest mean height. Table 5 gives the number of stands, families, and individuals involved in each selection scheme. There was an average of 9.2 individuals per family, therefore, when one individual per family is selected the selection intensity is 1.70 or 11 percent.

Table 5. Number of stands, families, and individuals selected and selection intensity for among and within families using Scheme I and II at the Highland Rim

Selection Scheme[a]	Number of Stands	Number of Families	Number Families and Individuals Selected	Selection Intensity	
				Family	Within Family
I	12	127	45	1.04	1.70
II	7	72	45	0.60	1.70

[a] Scheme I - selection of tallest individuals of the tallest 45 families of all stands.

Scheme II - selection of tallest individuals of the tallest 45 families of the best seven stands.

Components of variance used for the gain estimates of Scheme I were derived from an analysis of variance using all the families, but only families of the selected seven stands were used for Scheme II. The most striking difference among estimates of variance components for these two methods is the larger (27 percent) among family within stand variance for the selected seven tallest stands. Estimated genetic gains from the two proposed selection schemes are presented in Table 6. Both selection schemes give essentially the same gains. Gains from selection Scheme I and II were 0.74 and 0.77 feet, respectively, or 21 and 25 percent. This result compares well with the five percent estimated gain obtained from mass selection.

Table 6. Gains from family and within family selection and estimated mean heights of two-year-old progenies at the Highland Rim test site

Selection Schemes	Gains (feet) Family	Within Family	Total	Estimated Population Mean Height (feet)[a]
I	0.25	0.49	0.74	4.27
II	0.16	0.61	0.77	4.43

[a] Estimated second-year mean height of a population derived from random mating of selected trees.

LITERATURE CITED

Falconer, D. S. 1967. Introduction to Quantitative Genetics. The Ronald Press Company. New York. 365 pp.

Namkoong, G., E. G. Snyder, and R. W. Stonecypher. 1965. Heritability and gain concept for evaluating breeding systems such as seedling orchards. Silvae Genetica 15:76-83.

Snyder, E. B. 1969. Parental selection versus half-sib family selection of longleaf pine. Proc. of the 10th South. Conf. Forest Tree Impr. Houston, Texas. pp. 84-88.

Thor, E. 1964. Variation in Virginia pine. Part I: Natural variation in wood properties. Jour. Forestry. 62:258-262.

COMPETITIVE ABILITY OF SLASH PINE ANALYZED BY GENOTYPE X ENVIRONMENT STABILITY METHOD

E. B. Snyder and R. M. Allen[1]

Early genetic gains in growth rate may be offset by differential competitive ability when progeny test plantations close. Few tests are old enough, but one by Derr and Dell (1960) in a 22-year-old geographic slash pine (Pinus elliottii Engelm.) seed source plantation illustrates what may happen. There variation in diameter among sources was inversely correlated with 10-year survival. One can conclude that volume gains were reduced by stagnation of diameter growth caused by competition.

We followed Lazenby's (1965) suggestion that the genotype x environment stability method be used to study competitive ability and we adopted the methods of Perkins and Jinks (1968).

We observed the responses of 200 half-sib families of slash pine to favorable and unfavorable nursery conditions. Light and water were in short supply in the unfavorable environment, as they would be in a plantation with heavy intertree competition. Results, therefore, are interpreted as indicative of competitive ability; the best competing families will be retested through crown closure in plantations.

ANALYTIC METHODS

A given environment is quantified relative to other environments by the average performance of all the entries. Thus, an environment is described without defining or analyzing the complexly interacting edaphic and climatic factors. The deviation of each environmental value from the experimental mean are plotted on the abscissa of a graph. The environmental value is also subtracted from each phenotypic reading at that environment to establish the genotypic ordinate at the environment (Fig. 1).

Using the genotypic ordinate values of an entry across environments the entry's G x E mean square is determined. The genotypic values of each entry are also regressed against the environmental values, and the gross G x E mean square is subdivided into MS due to regression and MS

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[1] Principal Plant Geneticist at the Institute of Forest Genetics, Southern Forest Experiment Station, USDA, Gulfport, Mississippi, and Belle W. Baruch Professor of Forestry, Department of Forestry, Clemson University, Clemson, South Carolina, respectively.

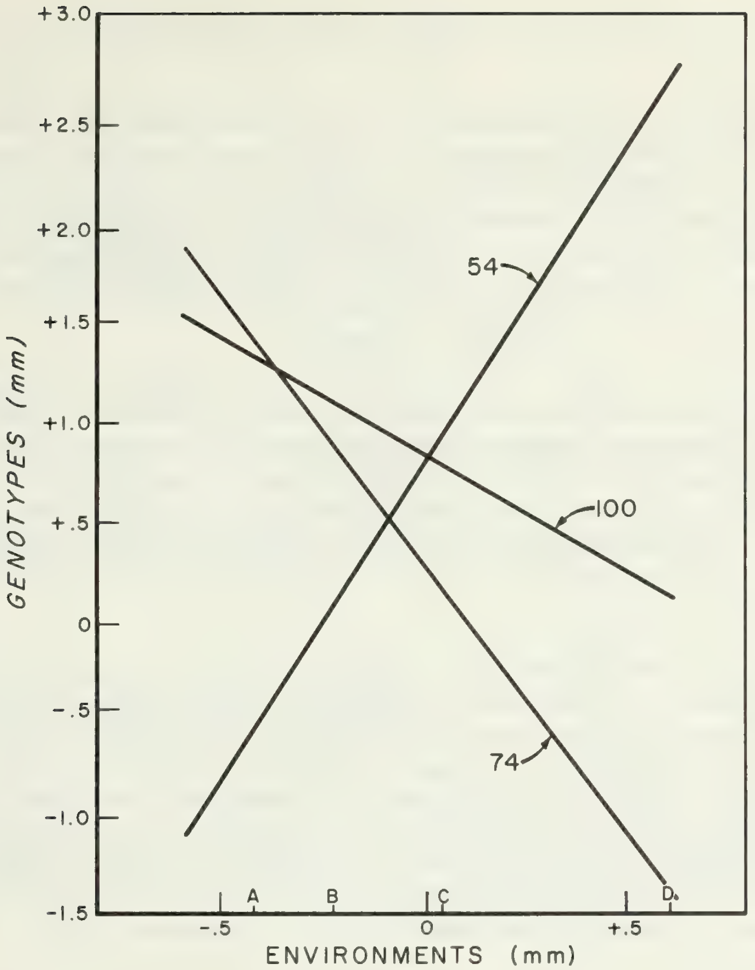

Figure 1.--Types of genotype x environment responses for diameter growth. A, B, C, D are the four environments.

due to deviations from regression. We wish to emphasize the separate regression analyses for each entry rather than the overall analysis. For the separate analyses, tests are made to determine whether each entry's response is linear. The error variance of the mean, calculated from the overall analysis of variance, is used to test the deviation MS, while the deviation MS of each entry is used as error for the respective regression MS. Tests for statistical significance were made at the 0.05 level of probability.

This regression analysis provides a prediction of relative performances in a range of environments; it does not have the disorderly behavior conveyed by the gross G x E interaction which has not been partitioned. An entry is regarded as desirable if it has a negative regression coefficient significantly different from zero. This condition signifies that the genotypic values of the entry are better, relative to that of the average entry, in poor environments than in good environments.

Entries that have no significant G x E interaction are less desirable since they are not responding to the environment in ways different from the average (regression coefficient = 0). Still less desirable are entries which deviate significantly from regression since their response is unpredictable. From our viewpoint, the least desirable entries were those with a significant positive regression.

BIOLOGICAL METHODS

In 1960 and 1961 wind-pollinated cones were collected from 200 randomly selected trees in southern Mississippi and southeastern Louisiana. In the spring of 1962, 400 sound seeds per tree were sown in 16 106-foot-long x 4-foot-wide nursery beds at the Harrison Experimental Forest. Nursery methods of Smith, Snyder, and Scarbrough (1963) were used, and the beds were treated with methyl bromide for weed control.

Adverse nursery treatments were imposed by either restricting light, water, or both, on each bed. The four combinations of light and moisture were each replicated four times and 200 families were assigned as plots to each bed. In each plot 25 seeds were sown in rows 12 inches apart running across the bed; each half row was a plot. A row of bulk slash pine seed was sown as a temporary buffer between each row of experimental material. Pretreatment height differences caused by faulty weed control persisted to the end of the experiment but were minimized by covariance regression adjustments.

In early August the study seedlings were thinned to six per plot and the shade-moisture treatments were imposed. Buffer rows were removed in mid-September and each plot was thinned to five seedlings.

Treatments were imposed by suspending polyethylene sheeting 30 inches above each bed. The sheeting was raised to 5 feet the second year. For the shade treatment the sheeting was covered with Saran shade cloth, which, with the sheeting, excluded two-thirds of the light. The high moisture beds were watered whenever available moisture in the surface 6 inches, as determined by Bouyoucos blocks, dropped below 95 percent. During the second season soil moisture dropped as low as 16 percent in the unwatered beds.

After 2 years average heights and diameters in the four environments were:

	Diameter (mm)	Height (cm)
A. Low light - low moisture	16.4	139.2
B. Low light - high moisture	16.6	134.6
C. High light - low moisture	16.8	143.9
D. High light - high moisture	17.4	143.4

Diameter values coded by subtracting the overall mean are shown on the abscissa of figure 1.

RESULTS AND DISCUSSION

The frequencies of the significant mean squares of interest from the 200 families were:

	Diameter	Height
Negative regression coefficient	7	6
Positive regression coefficient	8	2
Deviations from regression	10	11

For three families only the gross G x E mean square for height and diameter was significant. Entries having average response, not significantly different from zero, made up 86 to 89 percent of entries per character.

A yield-competition ability index was set up with mean diameter growth as the primary criterion. The best 25 percent, 50 candidates, were preliminarily selected (34 are shown in table 1). Half of these will be retained for additional testing. The half retained have one or more of the following attributes: (1) competitive ability in diameter as indicated by significant negative regression, (2) competitive ability in height, or (3) upper quartile rating in height. Those having significant deviations from regressions, i.e., nonlinear response, were not selected.

Three examples, graphed in figure 1, illustrate both the selection logic and the potentiality of the regression approach for uses other than screening for competitive ability (Morgenstern and Teich, 1969). Entry 54 with a slope of +2.59 was rejected because it grew poorly in adverse environments. It would be desirable where moisture and light are plentiful--the opposite of conditions in a dense stand.

Table 1.--Families in upper quartile class for mean diameter growth.

Entry no.	Mean (mm)	Regression coefficient		Nonlinear G x E response		In upper quartile for height growth	Selected
		Diameter	Height	Diameter	Height		
53	20.7	0	-0.72	--	--	+	+[1]
11	19.1	0	0	--	--	-	+
4	18.8	0	0	--	--	+	+
102	18.8	0	0	--	--	+	+
94	18.3	0	0	--	--	-	+
76	18.2	0	0	--	--	+	+
190	18.2	0	0	Sig	--	-	-[2]
158	18.2	0	0	Sig	--	+	+
178	18.2	0	0	--	--	-	+
6	18.2	1.01	0	--	--	+	+[3]
162	18.1	0	0	--	--	+	+
55	18.0	0	-0.37	--	--	+	+[1]
70	18.0	0	0	--	--	+	+
86	18.0	0	0	Sig	--	+	+[4]
78	17.9	0	0	--	--	+	+
45	17.8	0	0	--	--	+	+
96	17.8	0	0	--	--	+	+
36	17.8	0	0	--	--	+	+
104	17.7	0	0	--	--	+	+
25	17.7	0	0	Sig	--	-	-
13	17.7	2.33	0	--	--	-	-
54	17.7	2.59	0	--	--	-	-
14	17.7	0	0	--	--	+	+
51	17.6	0	0	--	--	+	+
137	17.6	0	0	--	--	+	+
120	17.6	0	0	Sig	--	-	-
37	17.6	0	0	--	--	+	+
77	17.6	0	-0.39	--	--	-	-[5]
93	17.6	0	0	--	--	+	+
90	17.6	0	0	Sig	--	-	-
118	17.6	3.52	0	Sig	Sig	-	-
100	17.5	-1.16	0	--	--	+	+[6]
101	17.5	0	0	--	--	+	+
160	16.6	-1.06	0	--	--	+	+[6]

[1] Good competitors for height.

[2] Rejected because of significant G x E and mediocre height.

[3] Poor competitor but high mean diameter.

[4] Selected in spite of significant G x E.

[5] Although a good height competitor, has low mean height.

[6] The only good competitors with reasonably high mean diameters. Entry 160, however, is slightly below the 25th percentile class for mean diameter.

The most successful competitor on the graph was entry 74 with a slope of -2.82. Breeding for families with a G x E interaction characterized by such a high negative slope appears to be a reasonable way of isolating good competitors. Unfortunately, this particular entry had mediocre mean growth which eliminated it. On the other hand, entry 100 was selected because it had a significant negative slope coupled with reasonable mean yield. Its slope is close to -1, which means that its phenotypic value is fairly constant from environment to environment. Such unvarying types have often been sought by plant breeders for planting over a range of sites.

Since we were selecting for performance under severe conditions, one might ask why we did not limit our progeny testing to severe conditions. The answer is that we wanted to determine if there are genotype x environment interactions. If there are none, conditions of the test are immaterial. If they exist, however, it is important to know whether the G x E interactions include three predictable types of responses: (1) strong negative regression coefficients--adaptation to competition; (2) coefficients near -1--adaptability to a range of environments; or (3) strong positive coefficients--adaptation to the more favorable environments. If genotypes are adapted to particular environments, we then agree that, as a next step, the conditions of the progeny tests should simulate only the special environments being bred for unless the -1 (stable) types or several simultaneous types are desired.

LITERATURE CITED

Derr, H. J., and Dell, T. R. 1960. Where should we get slash pine seed for Louisiana? Forests and People 10(2): 30-31.

Lazenby, A. 1965. Genotype and environment. J. Nat. Inst. Agr. Bot. 10: 274-287

Morgenstern, E. K., and Teich, A. H. 1969. Phenotypic stability of height growth of jack pine provenances. Can. J. Genet. Cytol. 11: 110-117.

Perkins, J. M., and Jinks, J. L. 1968. Environmental and genotype-environmental components of variability. III. Multiple lines and crosses. Hered. 23: 339-356.

Smith, L. F., Snyder, E. B., and Scarbrough, N. M. 1963. Care of pine seedlings used in breeding at Institute of Forest Genetics. USDA Forest Serv. Res. Note SO-2, 4 pp.

NURSERY MORPHOLOGY OF LOBLOLLY PINES AS AN INDICATOR OF FIELD PERFORMANCE

Hoy C. Grigsby[1]

Are easily identifiable morphological traits of nursery seedlings indicative of subsequent field performance? The study described here was designed to answer that question for loblolly pine (Pinus taeda L.). The value of a strongly affirmative answer is obvious. By sorting nursery stock, foresters would be able to establish plantations of trees with more uniform and perhaps more desirable features than heretofore. Results of the study do not suggest such striking possibilities, but some differences observed in the nursery were maintained in the field.

METHODS

Six distinctive and easily identifiable classes were set up for 1-0 loblolly pine seedlings in beds at an Arkansas Forestry Commission nursery in December (fig. 1):

Type 1. Normal winter bud not formed, no side branches, all needles primary.

Type 2. Terminal bud, no side branches, secondary needles of normal length. Typical 1-0 nursery seedling.

Type 3. Terminal bud, no side branches, secondary needles very long.

Type 4. Winter terminal and lateral buds formed and elongating, but no signs of buds breaking.

Type 5. Winter buds formed and open, shoots actively growing, tufts of short secondary needles formed at the tops of the buds. This phenomenon is known as lammas growth (Rudolph 1964).

Type 6. Terminal bud normal, at least one whorl of side branches present, secondary needles normal length. To eliminate possible confounding effects of additional growing space, no type 6 selections were made from isolated areas or from the border rows of beds.

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[1] The author is on the staff of the Institute of Forest Genetics, Gulfport, Mississippi, and is located at Crossett, Arkansas, as an Associate Plant Geneticist. The author expresses appreciation to Roland E. Schoenike, Associate Professor, Department of Forestry, Clemson University, for planning the study.

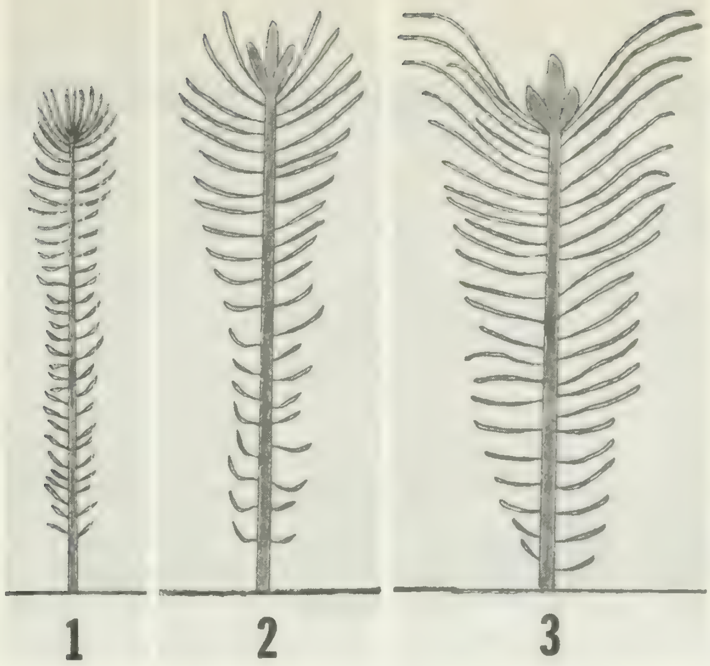

Figure 1.--Six types of 1-0 loblolly pine seedlings in December.

This numbering system arranges the seedlings in the order of apparent maturity at the time of selection. Type 1 is the least developed and type 6 the most fully developed.

About 5 million seedlings from local seed were observed in the nursery to obtain 504 trees--84 of each of the six types. Only seedlings conforming exactly to type description were selected. Observations in other nurseries have shown that all types occur frequently in loblolly pine beds. Twenty-one trees of each type were planted in randomized row-plots in four replications. The plantation was established in January 1958.

Trees were observed at the end of the third, seventh, and tenth growing seasons. At these times survival, height, number of branch whorls, number of branches per whorl, crown width, number of needles per fascicle, and length of needles were recorded. D.b.h. was measured only at the end of 10 years. Total cubic-foot volume inside bark was computed at age 10 by an equation from Schmitt and Bower (1970). All data were subjected to analysis of variance for randomized block design, and significant differences among means were determined at the 0.05 level of probability by Duncan's multiple range test (Duncan 1955).

RESULTS

Survival.--At age 10, survival by seedling type ranged from 75 to 82 percent (table 1). Types 1 and 2, the least developed at the time of planting, along with type 4, had the greatest survival. Type 5, which had the largest spurt of late growth, had the poorest survival.

Table 1.--Survival, by seedling type, at ages 3 and 10

Age	Seedling type					
	1	2	3	4	5	6
	Percent					
3	92	86	87	87	83	82
10	82	82	80	82	75	80

Branch number and length.--Type 6 seedlings, which were the only ones with at least one whorl of branches at the time of selection, had the greatest number of whorls throughout the study (table 2). Types 6 and 4 had significantly more whorls than type 1 after 10 years.

Table 2.--Branch whorls and branch number at age 10

Seedling type	Whorls per tree	Branches per whorl	Branches per tree
	Av. number		
1	14.35	4.78	68.59
2	15.94	4.66	74.28
3	16.05	4.60	73.83
4	15.94	4.84	77.15
5	16.80	4.56	76.61
6	16.87	4.70	79.29

Type 4, the fastest grower (table 3), had the highest number of branches per whorl and type 5 had the lowest. Type 6, which maintained the greatest number of whorls, was intermediate in number of branches per whorl (table 2). Type 1, the lowest in d.b.h. and next to the lowest in height, had next to the highest number of branches per whorl.

Table 3.--Relationship of crown width to tree height, diameter, and volume at age 10

Seedling type	Height	D.b.h.	Volume[1]	Crown width		
				Overall width	Per foot of height	Per inch of diameter
	Feet	Inches	Cu. ft.	Feet	Feet	Feet
1	28.67	4.88	1.465	12.19	0.4252	2.498
2	28.50	4.96	1.504	11.92	.4126	2.403
5	29.22	5.21	1.696	13.52	.4627	2.595
6	29.74	5.43	1.871	13.02	.4378	2.398
3	30.18	5.74	2.117	13.73	.4549	2.392
4	31.40	5.88	2.308	14.31	.4557	2.434

[1] Schmitt and Bower (1970), $V = 0.03789 + 0.0020911\ d^2h$.

Type 6, which developed branches while in the nursery bed, had the greatest number of branches. Even though type 1 seedlings grew slowly and had the least number of branches, there appeared to be little relationship between total number of branches and vigor.

Crown width was considered a measure of relative branch length at age 10. Average width varied from 14.3 feet for trees from seedling type 4 to 11.9 feet for type 2 (table 3). Types 4 and 3 had significantly greater width than types 1 and 2.

Crown width was significantly correlated with height growth ($r = 0.91$), with d.b.h. growth ($r = 0.91$), and thus with volume. On the basis of crown width per foot of height and per inch of d.b.h., trees from seedling type 5 had the greatest spread. It should be noted, however, that this type had the poorest survival and therefore the greatest growing space.

Needle length.--To test the variation in needles, several fascicles were examined on each tree. Differences in needle length existed at the time of selection, but at age 10 these differences were not significant and bore no relationship to growth or form.

Height, diameter, and volume.--The pattern of height growth during the 10-year period was fairly stable. Trees from seedling types 4 and 3 kept the number one number two spots, respectively, throughout the study. Types 5 and 6 have switched back and forth for third and fourth positions, and types 1 and 2 have done the same for fifth and sixth positions (table 3). At age 10, type 4 was significantly taller than 5, 1, and 2. Since the survival of type 4 seedlings was among the highest, height differences cannot be accounted for by growing-space differences.

D.b.h. differences, as expected, were similar to height differences at age 10, but were more pronounced. Between the largest and smallest seedling types there was a diameter difference of 17.0 percent and a height difference of 8.7 percent. Types 4 and 3 had significantly greater diameters than types 2 and 1. The difference between the averages for types with the smallest and largest diameter was exactly 1 inch (table 3).

Volumes ranged from 1.47 cubic feet per tree for seedling type 1 to 2.31 cubic feet for type 4 at age 10 (table 3). The volume of type 4 was significantly greater than those of types 5, 2, and 1, and volume of type 3 was significantly greater than those of 2 and 1.

DISCUSSION AND CONCLUSIONS

Trees from seedling type 5, which exhibited lammas growth in the nursery, had the poorest initial survival and were among the three poorest selections in terms of volume production. Romberger (1963) states that long buds or late shoots are triggered by a secondary increase in auxin yield. Whatever the cause, Rudolph (1964), working with jack pine (Pinus banksiana Lamb.) in the Lake States, concluded that trees with late shoots should be avoided in collecting seeds. The results of the present study indicate that loblolly pine seedlings with late shoots are undesirable if the condition is pronounced enough to produce lammas growth.

Some late growth appeared to be beneficial, however. Trees from seedling type 4, whose buds were elongated, were the fastest growing selections in terms of volume. Type 3, in which buds remained dormant after they were set, also grew well. Types 1 and 2, the least developed seedlings at the time of selection, grew slowest.

Survival at age 3 was correlated with seedling development at the time of selection. Types 1 and 2 apparently suffered less shock in transplanting, for they survived better than types 5 and 6, the most fully developed seedlings.

Limby seedlings (type 6) produced limby trees, and the extra branches did not appear to result in either broader crowns or more rapid growth than in other trees.

LITERATURE CITED

Duncan, D. B. 1955. Multiple range and multiple F tests. Biometrics 11: 1-42.

Romberger, J. A. 1963. Meristems, growth, and development in woody plants. U.S. Dep. Agr. Tech. Bul. 1293, 214 pp.

Rudolph, T. D. 1964. Lammas growth and prolepsis in jack pine in the Lake States. Forest Sci. Monogr. 6, 70 pp.

Schmitt, D., and Bower, D. 1970. Volume tables for young loblolly, slash, and longleaf pines in plantations in south Mississippi. USDA Forest Serv. Res. Note SO-102, 6 pp. South. Forest Exp. Stn., New Orleans, La.

COMPARISON OF SINGLE-CROSS AND POLYCROSS SLASH PINE PROGENY TEST RESULTS FOR RANKING SELECTED TREES

John F. Kraus[1]

To achieve the greatest gains from a tree breeding program it is necessary that the work continue over several generations. In order to maximize gains after the first generation it is almost imperative that some method be used of estimating the breeding value of the parents used in the establishment of second-generation seed orchards (seedling or clonal), or in speciality orchards. Depending on prior estimates of heritabilities or in some cases on experience in agronomic crops, there are three general approaches to progeny testing phenotypic selections of southern pines.

In clonal seed orchards the least intensive method of testing involves waiting until the seed orchard is in good general flowering, then collecting wind-pollinated seed from the various clones in the orchard and using them to establish progeny tests. We are hopeful these tests will be representative of the seed orchard production at maturity. A second method of testing clonal orchards is to control-pollinate the various seed orchard clones using a mixture of pollen from the selected trees; this pollen may be obtained either from the orchard or from the parent trees themselves when they are accessible. This method is generally more expensive than using wind-pollinated seed and may be more time consuming. The third method in common use is much more intensive and involves making controlled single crosses on the selected clones using four or five male parents as testers.

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[1] Principal Plant Geneticist, U.S.D.A. Forest Service Southeastern Forest Experiment Station, Macon, Ga.

If carried out under the right conditions, and with some forethought, all three methods should give reasonably good estimates of what is commonly called general combining ability. That is to say, that on the basis of the progeny test results we should be able to rank the seed orchard clones having the best to worst breeding values as female parents. The use of single crosses has the additional advantage that it should provide information on what is commonly called specific combining ability; that is, it should be possible to identify two clone combinations which are exceptionally good or poor. Presumably, the parents of these good crosses could then be used in orchards which would maximize the production of seed of the desired cross, and/or progeny from these crosses could be used as a source of second-generation breeding material. The early results reported here of a comparison of polycross and single cross progeny tests indicate that either method is suitable for the identification of the better parents for use in a breeding program, particularly for resistance to Cronartium fusiforme (Hedgc. and Hunt ex Cumm.)

MATERIALS AND METHODS

Fourteen clones being used in the Georgia Forestry Commission seed orchards were used as female parents in single crosses with five male testers. Of the 70 planned crosses, 60 were successful and eventually outplanted in an 8 x 8 balanced lattice design. Three of the female parents had been crossed with only three male testers while the remainder were successfully crossed with either four or five males.

The same fourteen clones had previously been polycrossed and outplanted in progeny tests. There were nine of these progeny test plantations, established in four different years. Seven are at either of two locations in the upper coastal plain, while two plantings are in the flatwoods. The polycross plantings are in randomized complete block designs usually with six replications of 25-tree-plots, or ten replications of 5-tree-row-plots. Some of the polycross progenies were planted in more than one test in a particular year, some in different tests in different years and some were in only one test.

In order to make this preliminary comparison of the two testing methods the average total height, average number of fusiform cankers per tree and the percent of trees rust free of the polycross and single cross progenies were compared by using their average performance relative to the commercial check lots in their respective plantations five years after planting. These relative values for each female parent were then compared using correlation analyses.

RESULTS

For all three traits examined the correlation of the mean performance of the single crosses with the performance of the polycross progenies planted in the upper coastal plain were highly significant (table 1). The best correlations were with the two measures of damage caused by fusiform rust.

In all but two cases the correlations were poorer when calculated on the basis of single crosses from only one male parent, indicating that no single male was consistently successful in providing a good estimate of the female parent's breeding value (table 1).

When the results from the polycross plantings in the flatwoods were also included the correlations for height and number of fusiform infections per tree decreased, while that for percent of trees rust free increased considerably. There is very likely a scaling effect in the percentage data since rank correlations of the same data also show a lower correlation for percentage rust free when polycross data from all plantings are used.

CONCLUSIONS

The data indicate that for the evaluation of parent trees polycrossing will give essentially the same results as single crosses using male testers. It is possible that open-pollinated progeny, particularly those produced in the orchard, would give the same result. In tree improvement programs in which large numbers of selected trees must be evaluated the use of single crosses may prolong the initial testing and eventually require estimation of missing cross values. It might be more advantageous particularly in these early stages to identify at least the best half of these selections available. Then use those selections in a single crossing scheme to combine good traits such as height growth and rust resistance, or to emphasize particular crosses aimed at substantial gains in one trait such as rust resistance. Progeny from these single crosses could then serve either as a source of later generation selections or could be used to establish seedling seed orchards.

Table 1.--Comparison of single-cross and polycross progeny test results at 5-years

	Average total height	Average number of fusiform infections/tree	Percent of trees rust free
	------------------	r	-------------------
Single cross mean vs. polycross, upper coastal plain plantings	0.700**	0.903**	0.808**
Male 1 vs. polycross, U.C.P.	.393	.854**	.806**
Male 2 vs. polycross, U.C.P.	.704**	.699**	.739**
Male 3 vs. polycross, U.C.P.	.548*	.594*	.767**
Male 4 vs. polycross, U.C.P.	.640*	.547*	.811**
Male 5 vs. polycross, U.C.P.	.222	.273	.673**
Single cross mean vs. polycross all plantings	.647*	.541*	.909**

*, ** Significant at the 0.05 and 0.01 levels of probability, respectively.

RESULTS FROM TEN LOBLOLLY PINE PROVENANCE TESTS IN TENNESSEE

George Rink and Eyvind Thor[1]

Ten seed source tests of loblolly pine in Tennessee (Table 1) were measured and analyzed for growth characteristics during 1969 and 1970. The provenance tests were evaluated to determine from which locations within the species range superior phenotypes should be selected for establishment of seed orchards of loblolly pine in Tennessee. In addition, five needle characteristics were studied to determine if needle variation follows regional patterns.

GROWTH RATE

Growth data from the ten provenance tests evaluated indicate that trees from the northeast part of the species range are best suited for planting in Tennessee. Loblolly pines from deep south Coastal Plain sources consistently showed the poorest growth. Trees from northeast sources had the fastest growth in height, diameter, volume of wood per tree and volume of wood per acre. The only exception was the South Carolina Piedmont source; trees of this provenance had the greatest volume growth per acre at the Ames plantation. This result was in part a reflection of unusually high survival, but South Carolina Piedmont trees also had good growth at the Chickasaw, Friendship and Highland Rim plantations.

The adaptability of loblolly pine for planting in Tennessee appears to be related to mean length of the freeze-free period of the seed source. Trees of provenances with between 190 and 210 freeze-free days (northeast sources) produced the most wood; this period corresponds to the mean freeze-free period of most of the provenance test locations. Provenances with freeze-free periods between 210 and 240 days (inland sources) produced trees with intermediate growth and trees adapted to longer freeze-free periods (deep south Coastal Plain sources) generally yielded the poorest results. Wood production expressed as tons per acre followed a pattern very similar to volume growth per acre. At Counce and Ames there was a very strong correlation between these characteristics with $r^2 > 98\%$. Figures 1 through 4 graphically depict mean wood production of trees from northeastern, inland and deep south sources in the Ames, Highland Rim,

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[1] Assistant in forestry and associate professor, respectively, Forestry Department, The University of Tennessee, Knoxville.

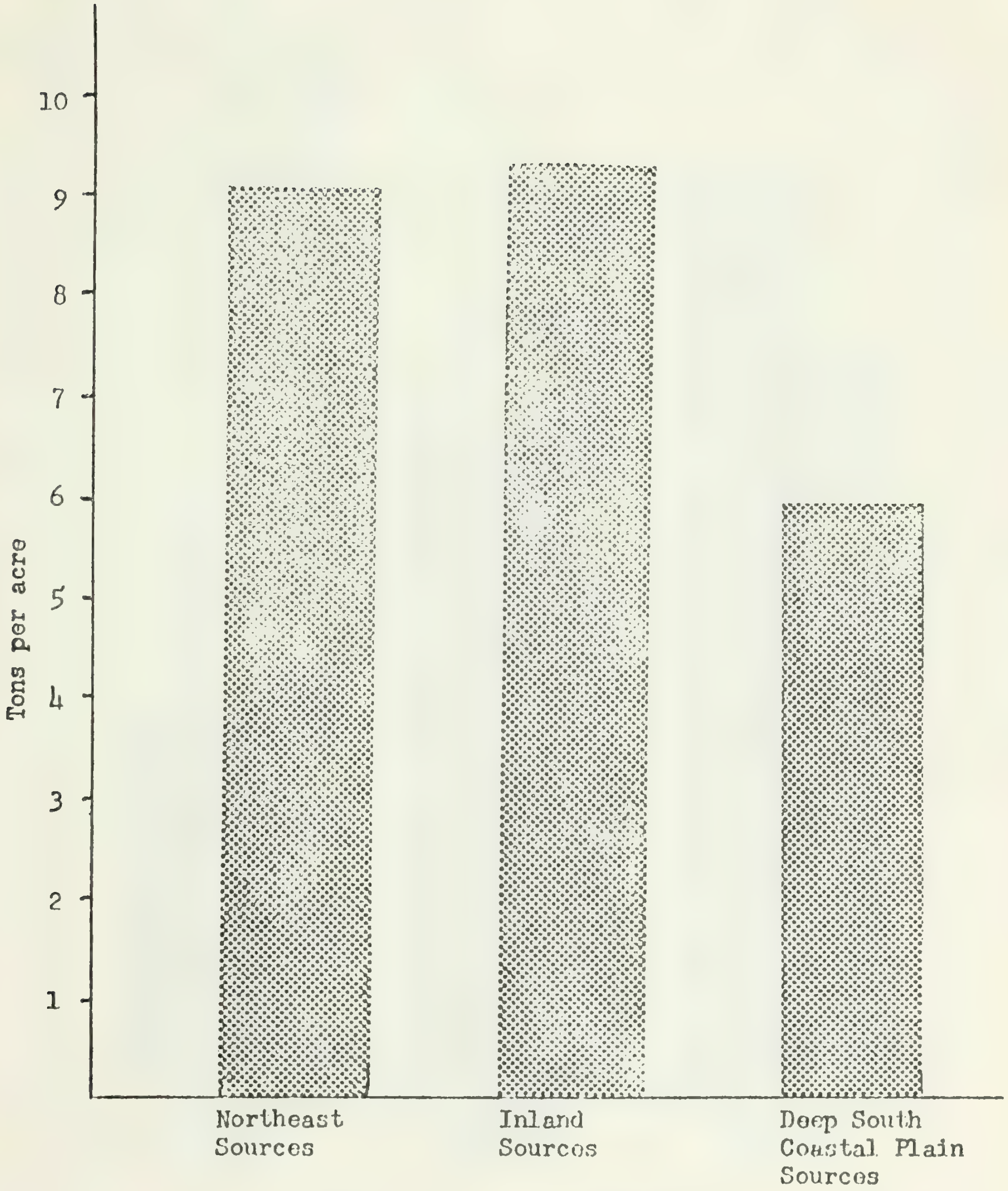

Figure 1. Wood production of loblolly pine from the three primary geographic provenance areas in nine years at the Ames Plantation.

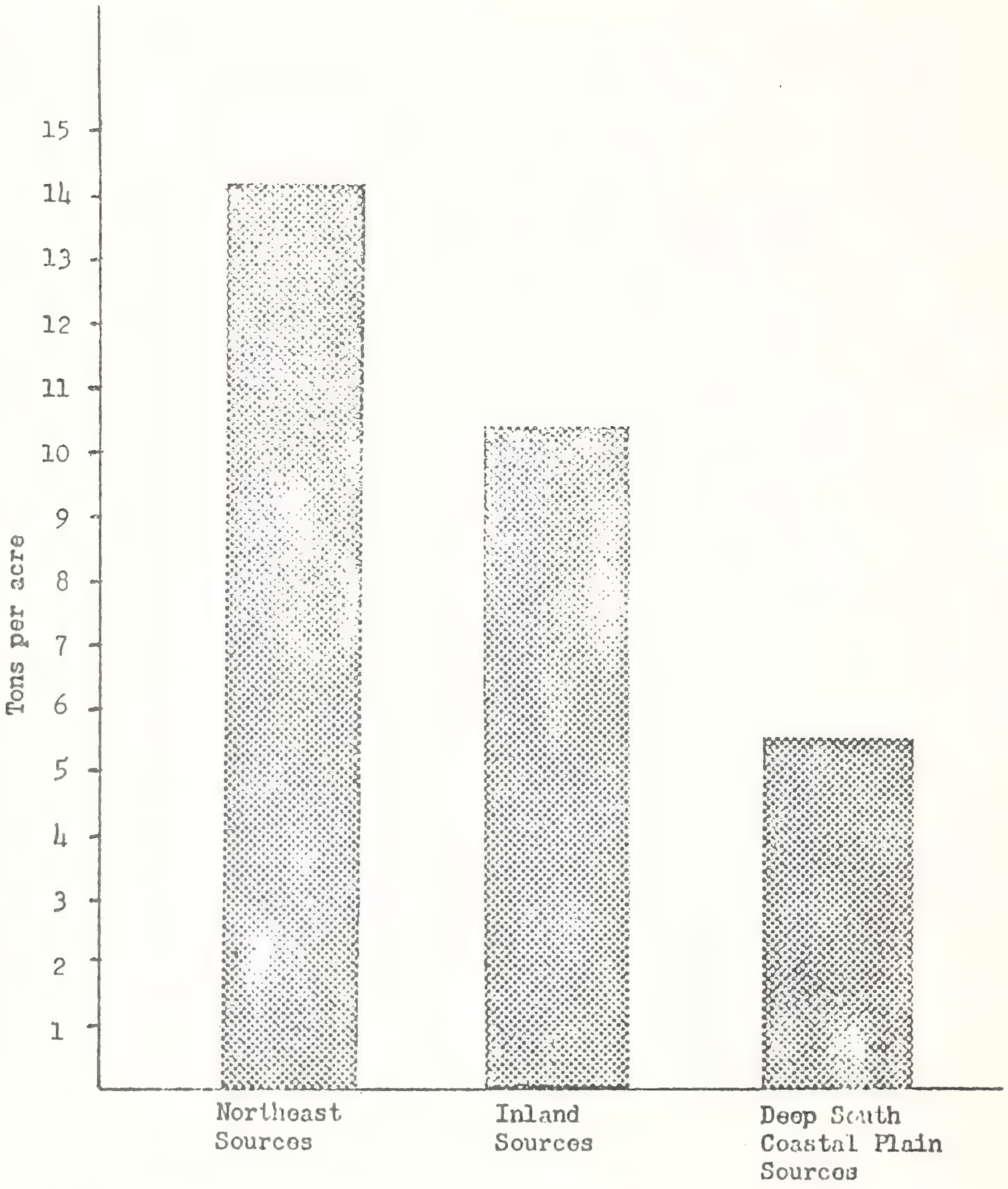

Figure 2. Wood production of loblolly pine from the three primary geographic provenance areas in eight years at Highland Rim.

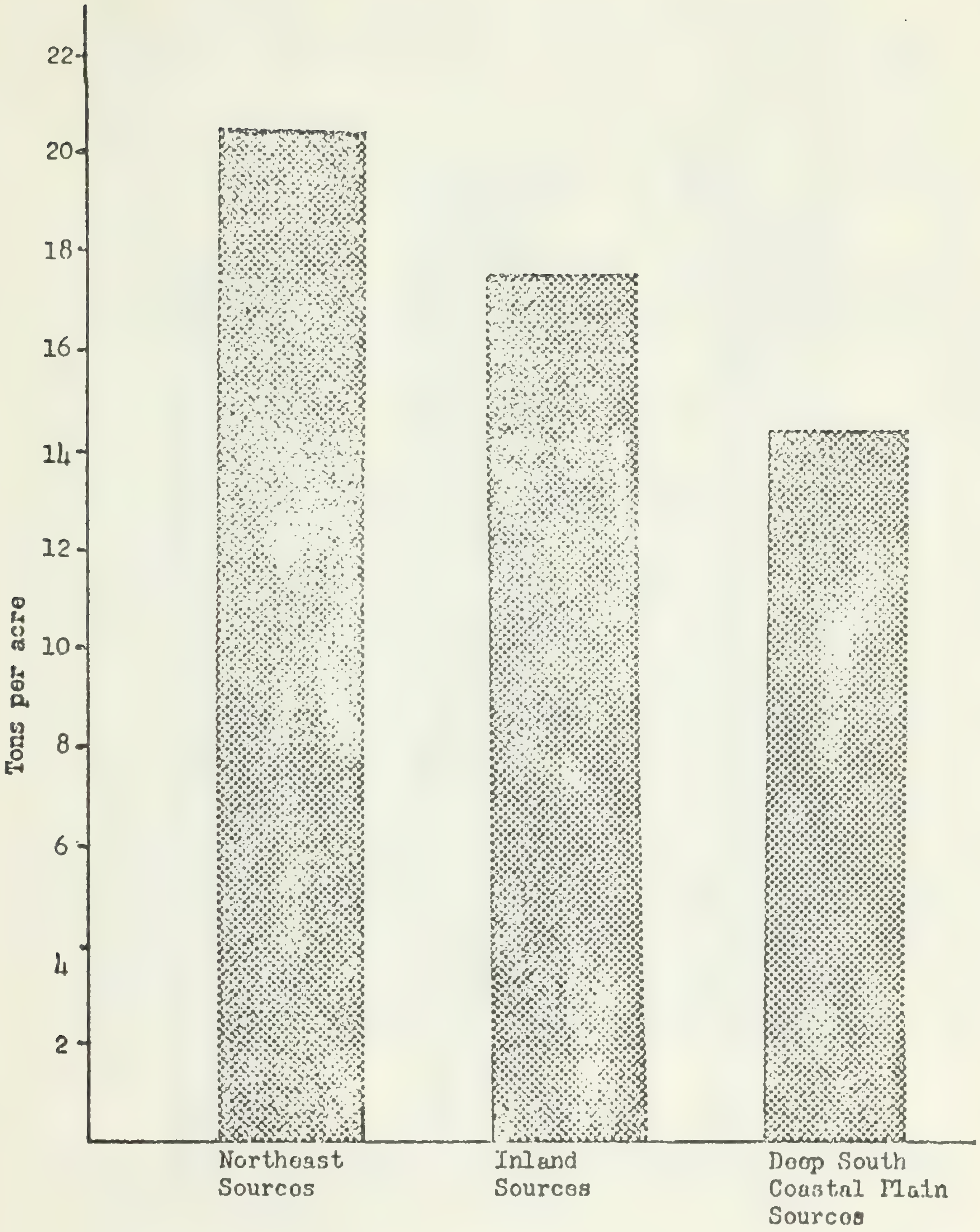

Figure 3. Wood production of loblolly pine from the three primary geographic provenance areas in ten years at Counce.

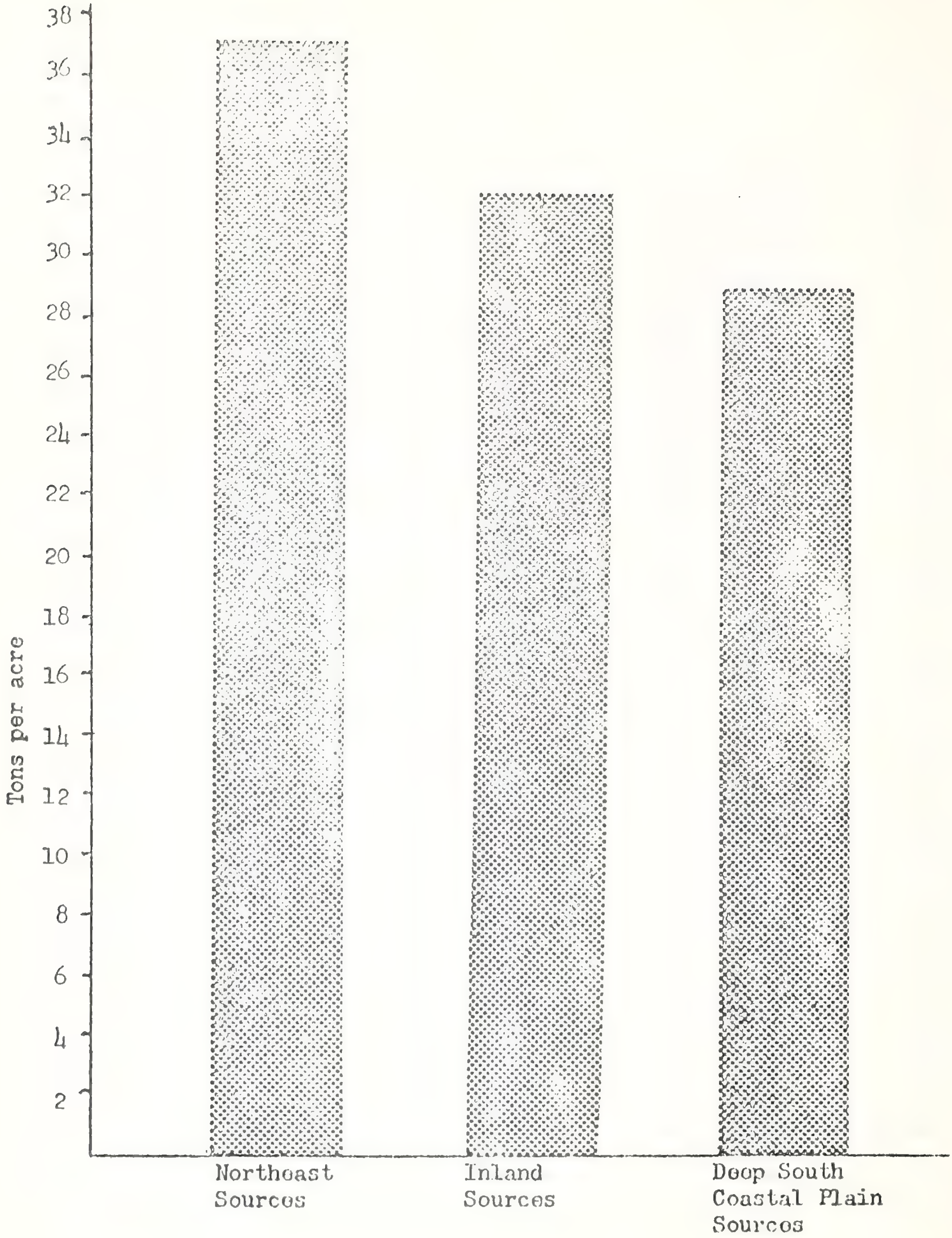

Figure 4. Wood production of loblolly pine from the three primary geographic provenance areas in fourteen years at Stephen's Switch.

Counce, and Stephen's Switch plantations. All sources north of and including North Carolina were combined into the northeast group, all Piedmont and inland sources south of North Carolina were in the inland group and all Coastal Plain provenances south of North Carolina were included in the deep south Coastal Plain sources. Histograms for the Highland Rim, Counce, and Stephen's Switch plantations indicate that the trees of northeast sources have the highest wood production. At Ames, however, trees from inland sources produced slightly more wood per acre than trees of the northeast sources. Ames is the most southwestern planting location and has the mildest climate of the four plantations. Higher wood production of trees from inland sources at Ames would, therefore, seem to support the hypothesis that adaptability of loblolly pines for planting in Tennessee is related to the mean freeze-free period.

WOOD SPECIFIC GRAVITY

Few significant differences among sources were found for specific gravity determined from 11 mm. wood cores (extracted with benzene and alcohol). However, there was a trend for trees from northeastern sources to have the highest specific gravity at five planting locations. Evidence for this trend appeared to be strongest at Ames where a Virginia Piedmont source was ranked highest and the Southern source lowest. This ranking was even more apparent when the Southern source was separated into its component Southwest and Southeast sources. Analysis of variance at this location now revealed significant differences among seed sources and the Duncan's Multiple Range Test indicated that trees from the Virginia Piedmont had significantly higher wood specific gravity than trees of all other sources. Trees of the Southeast source had significantly lower specific gravity wood than trees of all other sources. However, there is conflicting evidence from some of the other provenance test plantations; a southern source was ranked high with regard to specific gravity in four locations. Apparently the regional variation pattern for wood specific gravity is weak and not consistent with the patterns observed in studies of natural variation. The large among-tree variation and apparent genotype-environment interaction tend to confuse any regional pattern.

Correlation analysis for the 10-year-old Ames plantation (183 trees sampled) and the 15-year-old Stephen's Switch plantation (95 trees) disclosed no correlation between specific gravity and d.b.h. The well-known relationship between age and specific gravity was confirmed, with older plantations having higher values than younger plantations. At Ames the average specific gravity was 0.364, at Stephen's Switch 0.381 and the 20-year-old Norris-Loyston plantation averaged 0.406.

NEEDLE CHARACTERISTICS

Five needle characteristics were evaluated; number of needles per fascicle, needle length, number of stomatal lines per needle, number of serrations per centimeter of needle margin, and number of stomates per centimeter of needle length. The variation in number of needles per fascicle and needle length was apparently environmental; no geographic pattern was evident. Data for number of stomatal lines and number of serrations per centimeter indicate that trees from eastern sources have needles with higher numbers of stomatal lines than those of western sources, and that trees from inland sources have needles with higher serration frequencies than trees from coastal sources.

No geographic pattern for stomatal frequency was evident. However, needle data from the Ames plantation were significantly correlated (r=0.535) with data from parental trees observed in a 1958 natural variation study. This correlation implies the existence of some genetic control over the geographic variation in stomatal frequency.

CONCLUSIONS

Statistically significant growth differences were consistently obtained in only four test plantations. Three of these had the greatest number of sources represented. The only plantation with a large number of sources (eight) which did not yield significant differences among sources was the one at Norris-Loyston where only three replications were used as opposed to the four replications present in all other tests. In addition, statistical significance was obtained in provenance tests only where widely divergent sources were represented. Apparently, to detect differences among provenances where relatively similar seed sources are represented, either number of seed sources or number of replications must be increased.

Based on these data, it is recommended that most loblolly pines to be used in establishment of seed orchards in Tennessee should be selected from Maryland, Virginia, and North Carolina.

SEED ORCHARD DEVELOPMENT AND MANAGEMENT

Conferees

SEED ORCHARD MANAGEMENT

R. C. Kellison 1/

Papers pertaining to seed orchard establishment and management have been presented to this group for the past several years, e. g., Marler (1969), Vande Linde (1969), and Goddard (1967). These authors have discussed vegetative propagation, spacing, number, position, and isolation of clones within the orchard, and various cultural measures necessary to achieve acceptable tree growth and cone and seed production. Nothing would be gained by rehashing their conclusions, of which we are all in general agreement. Therefore, I shall restrict the contents of this paper to the most recent and most pertinent measures for increasing the production of seed orchards and to the colossal job of harvesting the seed. Thoughts are also presented on establishing and managing second-generation and two-clone seed orchards which are integral parts of present-day tree improvement programs.

MAXIMUM PRODUCTION FROM EXISTING ORCHARDS

The immediate need for genetically improved seed of the southern pines for the South's 600,000-acre annual regeneration program was a major consideration in favoring clonal seed orchards over other breeding approaches. A minimum of ten years was to be saved in obtaining the seed, but the savings in time was to be bought at the expense of less genetic gain than could be obtained from seedling seed orchards. From an economic standpoint, however, the time saved was considered more important than the genetic gain lost. Results to date from thousands of acres regenerated with genetically improved seed from clonal seed orchards verify the logic of that decision.

The advantages of clonal seed orchards are lost if there is not maximum seed production. Various methods have been used to increase production, including mutilation of both above- and below-ground parts of the tree, fertilization, irrigation, subsoiling and control of insects. Mutilation has not been successful; the most common result is loss of vigor or outright death of the tree. But for loblolly pine particularly there have been positive, sometimes dramatic, responses in tree vigor and in seed production from fertilization, irrigation, and subsoiling. Fertilization alone gives a twofold increase in seed production over nonfertilized treatments; and when combined with irrigation, a still greater increase is obtained (Gregory, 1968). Irrigation alone increases seed production only slightly except in droughty years when it means the difference between no seed crop and a heavy crop. It is concluded that an irrigation system will pay for itself every year in which droughty conditions prevail.

Subsoiling has become standard practice in many seed orchards of the South. It is considered essential to subsoil new orchards, particularly if the orchard site is abandoned agricultural or grazing land. It is equally essential to subsoil established orchards every four or five years to alleviate soil compaction caused by equipment traffic and to force the large, often exposed roots

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1/ Associate Director, Cooperative Programs, School of Forest Resources, N. C. State University, Raleigh.

of the orchard trees to develop at deeper levels where they will be less subject to invasion by insects and diseases. Without question, the practice enhances development of the orchard trees, and there is good reason to expect that seed production is also increased. Some reasons for the positive responses are better soil aeration, interception of surface water runoff, and a proliferation of roots into the trench.

Insect control in seed orchards is mandatory if seed production is to be maximized. Results from studies of mature loblolly and shortleaf pines in the N. C. State Cooperative Tree Improvement Program show a 30 percent loss of ovulate strobili to tip moths during one growing season when no control was applied. Indirect and direct destruction of strobili, cones, and seed by tip moths and other insects is even more severe on young seed orchard trees, often resulting in complete failure of seed crops.

Many of the commercial insecticides, particularly the systemics, have been effective in controlling the majority of destructive insects. But the effect they are reported to have on environmental pollution has already resulted in the banning of certain insecticides and others are in danger of being banned. It does not take great foresight to visualize the absence of pesticides in future seed orchard management. Since the pests will still be with us, perhaps in even greater numbers than are now present, what recourse will we have to producing genetically improved seed for the accelerated regeneration programs? Breeding for genetic resistance is one way; another is biological control of the pests; and still another is seed orchard expansion. The first two alternatives are long-term goals, whereas the latter can be made operational on short notice. It will not be surprising to see additional acres of seed orchard established to offset seed lost to insects and other pests.

HARVESTING SEED ORCHARD SEED

The N. C. State Cooperative Tree Improvement Program has been working for fifteen years and other organizations in the South have been working even longer to bring the 5500 acres of established seed orchards into commercial production. That day has arrived for the majority of those acres; but with it is a tremendous logistic problem in harvesting the seed.

The problem is a minor one for slash and longleaf pines whose mature cones, intact with seed, can be shaken from the tree by the high-frequency tree shakers. However, the tree shakers are ineffective for harvesting the cones of loblolly, Virginia, shortleaf and other southern pines because of the absence of an abscission layer in the cone's peduncle. The cones continue to cling to the tree or to broken limbs long after the crown has been completely denuded by the shakers. Abbreviated attempts to induce formation of abscission layers by the use of chemicals have met with failure.

If persistent cones, intact with seed, are to be collected, the only alternative is to collect them individually by cutting, twisting, or knocking them from their base of attachment. This is a slow and expensive task and one that loses its feasibility for orchards exceeding fifty acres. Owners of large orchards simply cannot marshal equipment and manpower in sufficient quantities to complete the harvest of cones in the ten to fourteen days between cone maturity and the start of natural dispersion of the seed. The season of harvest can be extended up to two weeks by artificially ripening the cones, but even this extension does not materially expand the area from which individual cones can be collected. The logical alternative to harvesting individual cones is to collect the seed after they shed from the tree-ripened cones. Methods investigated to accomplish this task include encasing the tree in tobacco cloth, lining the orchard floor with polyethylene or canvas, and erecting back-drops and funnels to catch the seed. For one reason or another, each method has proven unsatisfactory.

The most promising system to date is the vacuum sweeper which collects the seed from the ground after they have been shaken from the tree-ripened cone by the high-frequency shaker. A seed harvest committee operating within the N. C. State Cooperative Tree Improvement Program has devoted considerable time, effort and money over the past several years to the development of such a system. Tests conducted in the seed orchards of Union Camp Corporation in 1970[2] as a part of the action of that committee showed that the shaker removed 87 percent of the seed from the tree-ripened cones; and of those seed, nearly 100 percent were recovered by the vacuum harvester.

The vacuum harvester, as presently constructed, is not operational. Structural changes are needed to speed the operation, to make the unit more functional, and to engineer it for the rough terrain encountered in seed orchards. But the important point is that the principle of the system is sound; only structural modifications are needed to make the system operational.

Conditions necessary for the successful operation of the harvester in the seed orchards are a relatively smooth ground surface and a continuous grass cover that is free of coarse debris. Developing an orchard floor without excessive humps and depressions can be accomplished with a minimum of difficulty; the sweeper can recover seed from four- to six-inch-deep depressions. Maintaining a continuous grass cover is critical because without the grass the harvester picks up soil and rock particles in large quantities, creating maintenance and seed cleaning problems. A single-stem grass is desirable for complete recovery of the seed but is not essential if the sweeper follows closely behind the shaking operation. A side-delivery rake and a hay baler are satisfactory for removing the coarse debris from the orchard floor. The baled straw is ideal for mulching material, helping to offset the cost of cleaning the orchard.

The relatively slow speed at which the sweeper has to operate to assure complete seed pickup dictates the path of least resistance to cover the maximum area in a given time. In the seed orchards of the N. C. State Cooperative where initial spacing of the grafts is 15 feet in rows and 30 feet between rows and final spacing will be 30 by 30 feet, the path of travel is with the

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2/ Progress Report, Vacuum Seed Harvesting Test, 1971--Barry F. Malac and Marvin H. Zoerb, Jr., Woodlands Research Department, Union Camp Corporation, Savannah, Georgia. 28 pp.

rows for one sweeping and across the rows for the next sweeping; the interval between the two sweepings will be from seven to ten days. This procedure allows about 85 percent of the orchard area to be covered at each sweeping, resulting in some seed loss. However, this loss is more than offset by the time and effort encountered in double sweeping or in weaving among the trees. Since harvesting of cones and seed is the most demanding problem of seed orchard establishment and management, it is essential that this be considered in the design of future seed orchards.

SPECIALTY ORCHARDS

Tree improvement programs in the South have now progressed to the point that specialty and second-generation orchards are being established. Various of the specialty orchards such as improved first-generation,[3] disease resistant, and wet site orchards have a design similar to the present commercial production orchards and need not be discussed further here. They differ from rogued first-generation orchards in that the proven clones of the organization establishing the orchard plus the best of his neighbors' are included; rogued orchards are restricted to the base from which they were started. The conditions surrounding two-clone orchards and second-generation orchards are so unique, however, that some thoughts are given on methodology and design of establishment.

Two-Clone Orchards

Control-pollinated progeny tests of first-generation seed orchard trees reveal that specific combining ability of certain two-clone combinations is outstanding for certain characteristics. The most notable responses have been in volume production, tree form, and disease resistance. There is considerable interest in taking advantage of these specific combinations by establishing two-clone seed orchards, the progeny from which will be planted locally or on specific problem areas.

Problems encountered in establishing two-clone orchards are numerous. The ideal would be for progeny from specific combinations to be outstanding in all characteristics evaluated but this is rarely the case. Those that are outstanding in volume production may be less desirable in disease resistance, tree form, or wood properties; and those which are highly resistant to disease may be questionable for one or more of the other desired characteristics. The result is that sacrifices may have to be made for traits of least economic importance in order to favor those of greatest importance.

In addition to producing outstanding progeny, the two clones must be good strobili producers, they must be phenologically synchronized, and they must be relatively or completely self-sterile. Exceptions to the need for self-sterile clones would be when selfed progeny is equally good in all ways to the outcrossed progeny of the two clones and when an exceptionally good progeny for specialty use is produced from a two-clone combination, one of which produces inferior selfed progeny. In the latter case it would be advantageous to forego collection of seed from the selfing clone, at the expense of seed orchard efficiency, in order to obtain the special value seed from the second clone. Other essential attributes of the clones are graft compatibility, relative freedom from attack by insects and diseases, and responsiveness to the cultural measures used to increase seed production.

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[3] Locally referred to as 1.5-generation seed orchards

Phenological synchronization is more involved than the simultaneous maximum receptivity of the ovulate strobili of two clones. The staminate strobili of the two clones must also mature simultaneously and be in phase with female receptivity if there is to be a good seed set and if selfing is to be avoided. Results from a phenological study of Coastal Plain loblolly pine in Virginia (Wasser, 1967) showed maximum receptivity of the ovulate strobili among clones to differ by five days. Less variation was generally observed in time of staminate strobili maturity, but the pattern of maturity in relation to female receptivity indicated that problems could be encountered. Pollen of one clone was shed two days before maximum female receptivity, whereas it lagged behind female receptivity by three days on another clone. Choosing two such clones could spell disaster to a two-clone orchard.

The design of these specialty orchards will be dependent in large measure upon the flowering habit of the clones involved. If the two clones produce both male and female flowers in approximately equal proportions, the grafts of each should be alternated throughout the orchard. But if one parent produces pollen less profusely than the other it should be represented more frequently in the orchard to consummate cross-pollination. The ideal situation would be for one of the clones to be a good seed producer and a poor pollen producer and for the reverse to be true for the other clone. This would erase or minimize the possibility of selfing, and in addition it would allow the orchard to be operated for maximum seed production. To achieve this, the seed-bearing parent would be represented three to five times more frequently than the pollen parent.

The theoretical situation of selecting seed-producing and pollen-producing parents for the two-clone orchards is within reason. There are many clones in the seed orchards of the Cooperative Programs that possess one or the other of these extremes. The limiting factor to such a scheme would be the sacrifice of other factors essential to increased genetic improvement of such orchards.

Initial spacing of grafts in these specialty orchards is recommended for 20 by 20 feet, which would be increased to 40 by 40 feet after thinning. Results from production orchards of the Cooperative Programs indicate that cone and seed yields and seed germination is seriously impaired during the formative years of a seed orchard when pollen is at a premium. Spacing of grafts beyond 20 by 20 feet appears to aggravate the problem. Therefore, it seems economically sound to establish four times the number of grafts ultimately desired to assure a better supply of sound, germinable seed at a time when they are most needed. If seed- and pollen-bearing parents could be used in these orchards as suggested, an overabundance of the pollen-bearing grafts could be established with the knowledge that they would be thinned as pollen from the maturing grafts became more abundant. The grafts of the seed-bearing clone would remain as originally established.

Second-Generation Seed Orchards

Progeny tests of selected seed orchard parents of the southern pines are sufficiently progressed to allow initial selection of material for establishment of second-generation seed orchards. The procedure being followed is to select the best trees in the best families at age five. Criteria for selection are: volume production, insect and disease resistance, and crown and stem form. Those selections meeting the stringent requirements are then grafted into clonal banks where they will be observed for graft compatibility and reproductive fecundity, precociousness, and phenology. Reproductive behavior of the selections is deemed specifically important because of the fact that 80 percent of the seed obtained from the first-generation orchards is produced by only 20 percent of the clones. Those orchards are not only efficient seed producers but they also restrict recombination of some of the most productive genotypes.

During the interim of clonal evaluation, the original selection occurring in the progeny test will be left to grow until year nine when it will again be evaluated for the characteristics mentioned previously and also for its wood properties. If it has maintained its superior phenotype and if it has passed the strict clone bank standards, it is ready for inclusion in the second-generation orchard.

We anticipate the need for 200 select trees as a base for any given orchard. These will be obtained not only from the progeny tests of the cooperator establishing the orchard but also from the progeny tests of other cooperators within the same general region and from other sources of undetermined genetic worth. Before the latter group is accepted for orchard use their genetic worth will have been determined. The 200 selections need not be completely unrelated because only the best fifty will be included in the seed orchard. Selection of the fifty clones will be based upon pedigree, upon the continued performance of the select tree in the progeny test, upon performance of the graft in the clone bank and in the seed orchard, and upon progeny tests of the select tree. Grafts of the second-generation orchard will be established at a 20 by 20-foot spacing, with final spacing of 40 by 40 feet for the same reasons given for two-clone orchards. An orderly progression of recurrent selection as explained above for a second-generation orchard is dependent upon complete pedigree records. Results from our own studies indicate that general combining ability is so strong among forest trees that selection of second-generation material from mother-tree tests could lead to severe inbreeding depression. For example, every seed orchard in the N. C. State Cooperative has one or more good general combiners. It is not uncommon for 80 percent or more of the best performing trees in control-pollinated progeny tests of these orchards to have one of these good general combiners as a parent. We are not sure how much inbreeding can be tolerated in forest trees but it is inevitable that problems will be encountered in future generations of breeding, if not in the present one, if the pedigree of the breeding stock is ignored.

Mass collections of scion material will be available from the clone bank material and also from the select tree for grafting. Evidence indicates that these second-generation selections which will be no more than twelve years old at time of establishment in the orchards will commence flowering profusely soon after grafting. Management of the second-generation orchard will be similar to that being practiced in the present commercial production orchards.

EFFECTS OF SEVERAL LEVELS OF INBREEDING ON GROWTH AND OLEORESIN YIELD IN SLASH PINE

Charles R. Gansel[1]

Effects of selfing on seed set, germination, and early growth for many species of trees have been summarized by Franklin (1970). Many tree breeders are now making second generation selections and are becoming more interested in the inbreeding effects of backcrossing and sib mating.

One selection method employed in establishment of second-generation orchards is combined selection in the progeny tests. If more than one individual is selected from a family, full-sib or half-sib matings can result. If the best original selections are also added to the new orchard, then backcrossing becomes possible. Knowledge of the effects of these different levels of inbreeding is needed in order to predict seed production and subsequent tree growth. This paper presents data on the effects of selfing, sib mating, and backcrossing on growth and oleoresin yield of slash pine (*Pinus elliottii* Engelm.). Earlier results from this study on effects of inbreeding in slash pine were reported by Squillace and Kraus (1962).

EXPERIMENTAL PLOTS

The main study plot (Study G-38A) was outplanted near Olustee, Florida, in January 1962. It consisted of 17 full-sib families planted in 2-tree plots replicated 10 times. Five mating types were represented: outcross, half-sib, full-sib, backcross, and self. Study G-38B is a supplement to G-38A. It contains 4 blocks with 1 to 14 trees per family per block and was planted the same time as G-38A. Study G-38C was planted 1 year later and contains single tree plots with 10 replications. Wind and polycross progeny of the selfed selections are compared with self progeny.

In addition, data obtained from two other studies are also included. From short-term progeny tests (Studies G-58 and G-62), height growth, stem diameter, and oleoresin yield of progenies resulting from two levels of inbreeding were compared with outcrossed progenies. Both studies contained 3-tree family plots with 12 and 8 replications, respectively. Data are from third year measurements. Trees varied from 5 to 15 feet and averaged 10 feet in height. Special care was taken of these outplantings so very few seedlings were lost. Those with depressed growth were still present at the time of final measurement. Study G-58 was a diallel cross of eight selections but lacked most reciprocal crosses. A mean was determined for the progeny of each self as was a mean for the outcrossings of that self. They were then combined for comparison (Table 1). Study G-62, compares 35 backcrosses with a like number of outcrosses. Both studies received intensive care including cultivation, fertilization, and irrigation. Insect damage was kept to a minimum by chemical control.

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[1] Associate Plant Geneticist, Southeastern Forest Experiment Station, U. S. Department of Agriculture, Naval Stores and Timber Production Laboratory, Olustee, Florida.

Table 1.--Progeny means for height, stem diameter, volume, and oleoresin yield for different types of matings when compared with outcrossing.

Type of mating	Number of Families	Theoretical Inbreeding Coefficient	Height	Stem[1] Diameter	Volume	Oleoresin Yield[2]
			Feet	Inches	Cu. ft.	Grams
			Study G-38A (9th year measurements)			
Outcross	3	0	34.5	5.7	2.37	329
Half-sib	4	0.125	31.8	5.1	1.85	323
Full-sib	2	0.25	30.5	4.7	1.51	298
Backcross	6	0.25	30.8	4.9	1.69	299
Self	2	0.5	32.5	5.5	2.32	360
			Study G-38B (9th year measurements)			
Outcross	3	0	31.5	5.4	2.12	285
Self	4	0.5	25.5	4.2	1.00	233
			Study G-38C (8th year measurements)			
Outcross	5	0	25.7	4.7	1.05	
Self	3	0.5	13.3	2.1	.21	
			Study G-58 (3rd year measurements			
Outcross	34	0	9.9	2.0		4.5
Self	8	0.5	7.1	1.4		2.6
			Study G-62 (3rd year measurements)			
Outcross	35	0	10.4	2.1		4.3
Backcross	35	0.25	8.9	1.8		3.8

[1] Stem diameter in Studies G-38A, B and C was measured at breast height but in studies G-58 and G-62, it was measured 6 inches above ground line.

[2] Oleoresin yields for Studies G-38A and B are based on flow from 4 one-inch square microchips made at two week intervals and treated with a 50% sulfuric acid solution to prolong flow. Yields from Studies G-58 and G-62 are from a triangular mini-chip (.95 sq. cm) treated with a small bead of sulfuric acid paste along the top side and left for one week.

RESULTS

Inbreeding depression in height, d.b.h., and volume is evident in the 9-year-old plantation and is proportional to the degree of inbreeding (Table 1). Oleoresin yield shows considerable variation in inbreeding depression.

Inbreeding depression in height, stem diameter, volume and oleoresin yield compared to outcrosses for the different degrees of inbreeding is presented in Figure 1. For height growth, this is in close agreement with the previous results by Squillace and Kraus (1962), who reported an approximate 4% decrease for each 0.1 increase in inbreeding coefficient. These findings were also in agreement with what Langner 2/ found in studying Japanese larch; that is, a 5% decrease for each 0.1 increase in inbreeding coefficient.

Figure 1 indicates little change in inbreeding depression with age for height or diameter growth. The younger and older plantation data follow the same pattern. A report by Snyder (1968) and subsequent studies conducted at Gulfport, Mississippi (personal communication with Snyder, May 1971) expressed the possibility of a severe change in inbreeding depression with age. However, there are too few selfed individuals in this study to resolve this question.

CONCLUSIONS

Inbreeding caused a significant and predictable depression on tree growth in these studies. Effects of backcrossing, full-sib and half-sib matings may be of more importance in a plantation than selfing. The reason for this is that fewer seedlings are produced from selfs (Snyder, 1968 and Franklin, 1970) and of those planted, many do not compete in the stand due to the severe inbreeding depression. Seedlings produced from backcrossing and full- and half-sib matings are more numerous and less depressed in growth than are self seedlings, so more remain in the stand longer and can result in decreased fiber production.

Oleoresin yield and growth are positively correlated so when growth is adversely affected so is oleoresin yield. Ideally, there should be no inbreeding in seed orchards. However, from a practical standpoint, this is not possible so the next best thing is to minimize inbreeding.

2/ A 10-page mimeographed reproduction of a report prepared for Sec. 22, IUFRO, 13th Congress at Vienna, 1961: "Einige Versuchsergebnisse zum Inzuchtproblem bei der forstlichen Saatgutgewinnung," by W. Langner, Institut fur Forstgenetik und Forstpflenzenzuchtung in Schmalenbeck.

RECOMMENDATIONS

The following suggestions are offered to seed orchard managers as ways to minimize inbreeding when establishing new seed orchards:

1. Know the parentage or origin of all selections in the orchard.
2. Use at least 20 clones, preferably 50 to 100, for establishment of seed orchards.
3. Use seed orchard designs which maximize distance between ramets of the same clone and/or related clones.
4. Avoid using related clones in the orchard whenever possible.

When establishing your new seed orchards, don't underestimate the adverse effects of inbreeding.

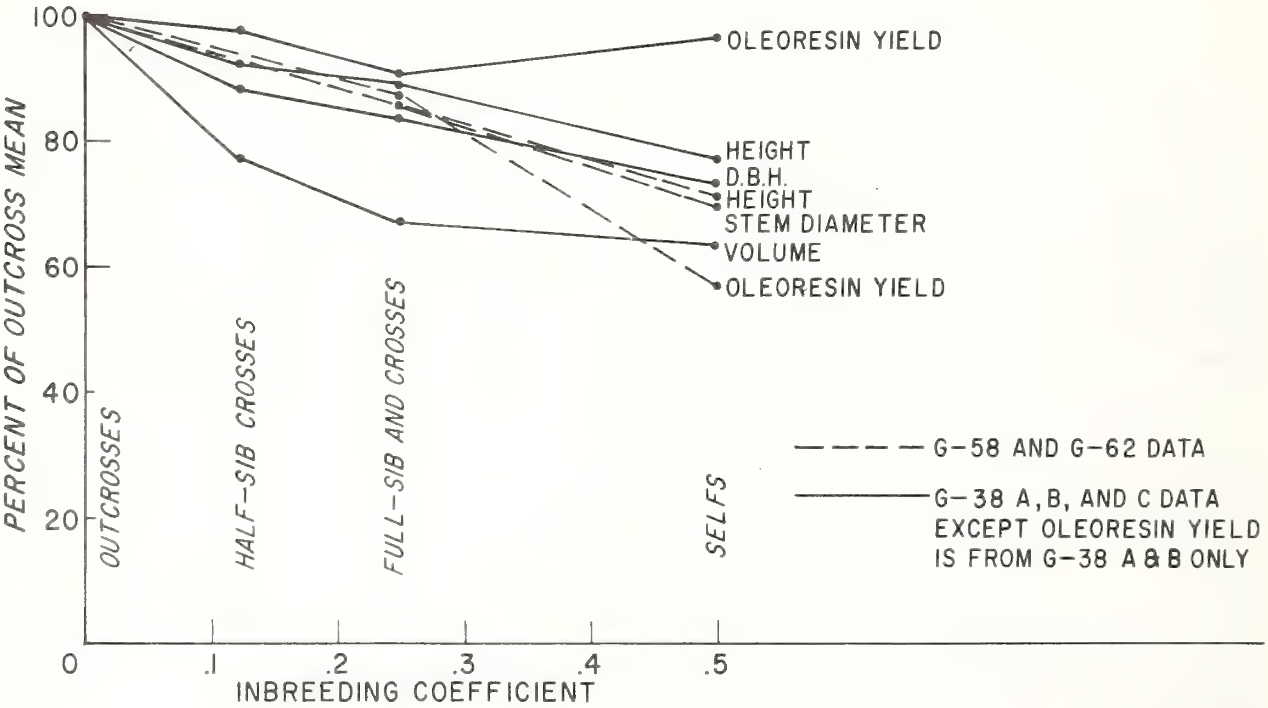

Figure 1.—Effect of inbreeding on growth and oleoresin relative to outcrosses means.

LITERATURE CITED

Franklin, E. C. 1970. Survey of mutant forms and inbreeding depression in species of the family Pinaceae. Southeast. Forest Expt. Sta., USDA Forest Service Res. Pap. SE-61. 21 pp.

Snyder, E. B. 1968. Seed yield and nursery performance of self-pollinated slash pines. Forest Sci., Vol. 14: 68-74.

Squillace, A. E. and Kraus, J. F. 1962. Effect of inbreeding on seed yield, germination, rate of germination, and seedling growth in slash pine. "Proceedings of a Forest Genetics Workshop", October 25-27, Macon, Georgia.

THE VALUE OF INSECT CONTROL IN SEED ORCHARDS: SOME ECONOMIC AND BIOLOGICAL CONSIDERATIONS

Gary L. DeBarr [1]

There are more than 6000 acres of clonal pine seed orchards in the southern United States, with additional acreage being established each year. The projected capital value, at age 15, of the orchards already established, is estimated at over 30 million dollars. For the orchardist managing these valuable pieces of forest real estate a critical facet of his job is the protection of the orchard and its annual crop of superior seed from devastating insect attacks. To meet this responsibility the seed orchardist has to decide whether or not to use insect control measures, and asks himself the question, "What will insect control buy for me in my orchard?"

Protection of the large, per-acre, capital investment in the orchard, and its annual seed crop justify the use of insect control methods far too costly to employ under normal conditions of forest management. Thus, insecticides are applied in seed orchards to protect new grafts, as well as to reduce cone and seed insect populations, and in turn, increase seed yields. Because they were cheap, readily available, and had excellent residual properties, the organochlorine insecticides were first used in seed orchards; DDT to control tip moth, *Rhyacionia* spp., BHC for the coneworms, *Dioryctria* spp., and heptachlor against the flower thrips, *Gnophothrips fuscus* (Morgan). More recently dimethoate and phorate have been used for tip moth, azinphosmethyl (Guthion®), for coneworms and seedworms, *Laspeyresia* spp. (DeBarr and Merkel 1971) and malathion for thrips (DeBarr and Matthews 1971). These "non-persistent" organophosphate insecticides are more rapidly metabolized, and thus have shorter effective biological half-lives. They are also more expensive.

Seed orchards vary as to tree species, age, productivity, location, size, prevalent species of destructive insects, and diversity of management practices employed. But, how much can be spent to control insects in an orchard, and still make the operation economically justifiable? It should be obvious that the complexity of the problem precludes any hard-fast rules. To answer the question of what we are "buying" through the control of seed orchard insects, in terms of protection of the capital investment in the orchard, or increased productivity, a number of factors must be considered.

PROTECTING THE SEED ORCHARD FROM INSECTS

Excluding the costs incurred in searching for and selecting superior parent trees, the initial investment in growing root stock, grafting, and planting a new seed orchard, ranges from $1.00 to $3.00 per tree. Operation and management costs during the unproductive establishment period along with a reasonable rate of return on the investment, results in a high capital value, per acre of seed orchard, by the time the orchard reaches the age of initial commercial production. Davis (1967), working with data from a 100-acre and 40-acre loblolly pine seed orchard, predicted that if they reached commercial production at 15 years of age, their capital value would be $4728 and $7636 per acre, respectively. Thus, at age 15, each tree in the seed orchard represents an investment of $100 to $150.

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[1] The author is research entomologist at the Forestry Sciences Laboratory, which is maintained at Athens, Georgia, by the Southeastern Forest Experiment Station, Forest Service, U. S. Department of Agriculture.

Insects cause varied types of injury to all the tree species currently included in the South's tree improvement programs. For example, Smith (1954) reported that a small bark beetle, *Pityophthorus pulicarius* (Zimm.) attacked the scions of slash pine grafts. This beetle is a potentially serious pest in the South, and has killed as high as 25 percent of the grafts in a newly established orchard. *Dioryctria* spp. are important insects devastating southern pine cone crops, but they also are responsible for other types of damage. In newly-planted seed orchards, *D. amatella* pitch masses are found near the graft union (Fatzinger & DeBarr, 1968). In older orchards, the larvae also bore into the crotches between limbs and the main stem, or enter through mechanical wounds in the bark such as those caused by tree shakers. This feeding can cause the branches to break off, and in some cases the entire upper-tree crown is destroyed. These are but two examples of insects that have already become important seed orchard pests because they indirectly affect seed production by distorting, or killing the seed-producing tree. It does not require any extensive calculations to determine the economics of protecting 15-year-old trees worth from $100 to $150 each.

Many other insects are occasionally encountered in seed orchards. Aphids and scale insects, for instance, are often found sucking the juices from the buds, branches, and needles of fast-growing seed orchard trees. Their feeding activity undoubtedly weakens the tree, but the effect upon the ultimate goal of maximum seed production is unknown. Investments in control for such less threatening insects is currently questionable.

PROTECTING THE SEED CROP FROM INSECTS

The high value of individual trees within a seed orchard makes it easy to justify the use of almost any conventional control method to protect them from insects. But, the problem of how much can be spent to protect the annual seed crop from insects is not as easily resolved. Controls must be examined in terms of their potential to increase seed yields. However, for most research results on cone and seed insect control, the degree of control obtained is expressed in terms of decreased insect infestation, i.e. the percentage the infestation is reduced as a result of the control. There are two primary reasons we examine infestation levels, rather than seed yields. First, data on the degree of insect infestation are often much more easily obtained than data on seed yields. Secondly, most research studies are conducted to demonstrate that a particular control method or chemical has the potential to prevent insect infestations, rather than to determine if the method or insecticide is economical.

According to the economic principle of Marginal Cost and Marginal Revenue, expenditures are economically sound, as long as the marginal revenue for each unit of output is of equal or greater value than the cost incurred in its production. This production cost should also include a return on the investment in the control, at the firm's guiding rate of return. Essentially, this means that in a seed orchard an insect control program is economical, as long as the costs, including interest on the investment, are less than or equal to the value of the increased seed yields.

Because of the diversity among seed orchards and specific insect problems, as well as variation in management practices and objectives, a control method that is economical in one orchard may be too expensive to justify in another orchard. There are at least four important factors that an orchardist might want to consider before deciding whether or not controlling cone and seed insects will "buy" anything in his particular orchard.

Value of the seed

First, the orchardist must know the value of the crop he is trying to protect. It is difficult to place a value on seed produced in clonal seed orchards since the final assessment of the genetic improvement realized from selecting and breeding trees with superior qualities is yet to come. Barber (1963) used initial measurements of progeny from clonal orchard parents to arrive at a 5 to 10 percent or more increase in growth and yield over current yields. Marler (1963), considering the factors of better adaptation of seed to the site, better disease resistance, and improved wood quality, as well as increased growth in straighter more vigorously growing trees, stated that it is entirely realistic to expect at least a 5-percent overall improvement from current seed orchard programs. Perry and Wang (1958) worked out the expected increase in profits from growing trees of various assumed degrees of genetic superiority in a pulpwood rotation. Based upon calculations in their example, a two percent genetic improvement would permit an expenditure of $18.90 extra per pound of seed over and above the cost of wild-type seed, and still allow a 5-percent interest profit annually. A five percent genetic improvement would allow an expenditure of approximately $40 per pound. Davis (1967) used data from two loblolly pine seed orchards to determine the investment costs of improved seed, or what he refers to as "the difference in price between what the forest manager would have to pay for improved seed and what he would have to pay for ordinary seed." He stated that a gross cost of $15 per pound of improved orchard seed was the best single estimate that could be made on the limited base of his study.

Estimate of the expected yield

Secondly, the orchardist must make a reasonable estimate of the expected yield in his orchard. Cone crops will probably increase in size until an orchard reaches the age of maximum productivity and then they will fluctuate from year to year. In addition, certain clones within an orchard will be more prolific cone producers than others.

Estimate of the expected seed losses to insects without control

Third, the orchardist must have an idea of the seed losses he can expect, if he does nothing at all to control cone and seed insects in his orchard. He can rely upon loss data from the previous years cone crop. Another way to obtain the data is to leave some trees in the orchard untreated, to serve as checks. If the latter method is used, it should be kept in mind that for an accurate evaluation the check trees must be isolated from the effects of existing control measures. Also remember that certain clones appear to be more susceptible or resistant to cone and seed insects.

How good is the control method

Finally, the orchardist must be aware of the degree of insect control he can expect from any particular control method. No control method currently available will consistently provide complete elimination of the damage caused by any particular cone and seed insect. There are, however, several control methods which when properly applied, will reduce insect damage by 95 percent or better.

Information on each of the four factors discussed is necessary to make a knowledgeable decision as to "what cone and seed insect control is buying, or can buy, in terms of increased seed yields." Two examples will illustrate one way to approach the problem of evaluating the economics of cone and seed insect control.

The first example is based upon data published by Merkel and Yandle (1965). Their study was conducted to determine the effectiveness of three treatments for controlling coneworms, *Dioryctria* spp., and the slash pine seedworm, *Laspeyresia anaranjada* Miller, infesting second-year, slash pine cones. Briefly, the sprayed trees received three applications of one of the following treatments: (1) 0.5-percent BHC (hydraulic sprayer); (2) 2.5-percent BHC (mist blower); and (3) 1.0-percent Guthion® (mist blower). An average of 8.5 gallons of insecticide-water emulsion was applied per tree with the hydraulic sprayer, compared to 1.0 gallon per tree with the mist blower. The cost of the insecticide alone for 3 hydraulic spray applications was \$2.40 per tree compared to \$1.44 per tree for 3 mist blower applications. On unsprayed trees second-year cone attacks by *Dioryctria* spp. averaged 30 percent, while an additional 30 percent were infested by *Laspeyresia*. Control of *Dioryctria* and *Laspeyresia* resulted in a seed-yield increase of from 0.5 to 1.2 lbs. per tree (Table 1). Assuming a value of \$15.00 per pound, the additional seed yield per tree, obtained as a result of insect control, was worth from \$7.50 to \$18.00, depending upon the treatment. Labor costs, equipment investments, and a return on the investment at the firms guiding interest rate would have to be taken into account to decide if control was economically sound.

Table 1.--Slash pine seed yields from various treatments to control seedworms and coneworms 1/

Treatment	Average seed yield/ cone	Average yield of seed/ tree 2/	Increased seed yield/tree over checks		Value of seed/ tree 3/	Value of the increased seed yield/tree
	- - Number - -	- Lb. - - -	Lb.	(Percent) - -	- - Dollars	- - - -
0.5% BHC-hydraulic sprayer	118	2.1	1.2	(133)	31.50	18.00
2.5% BHC-mist blower	87	1.6	0.7	(78)	24.00	10.50
1.0% Guthion-mist blower	78	1.4	0.5	(56)	21.00	7.50
Check-no spray	53	0.9	--	--	13.50	--

1/ Based upon data from Merkel and Yandle (1965).

2/ Based upon an average of 250 cones/tree and assuming an average of 14,000 slash pine seed/lb.

3/ Assuming a value of $15.00/lb. of seed.

A second example also involves the control of *Dioryctria* and *Laspeyresia*. It is based upon data from a recent study involving trunk implants of the systemic insecticide, Bidrin® (Merkel & DeBarr -- In Press). Briefly, 70-foot-tall slash pines in a seed production area, were implanted with 5 grams of Bidrin® technical liquid per inch of diameter at d.b.h. A single implantation of the systemic was made during May of 1967. Thirty percent of the cones on the untreated trees were infested with one or more seedworm larvae, and yielded an average of 74.6 seed/cone (Table 2). The Bidrin® treatment resulted in a 84-percent reduction in the number of seedworm infested cones, and a 15-percent increase in seed yield per tree. *Dioryctria* infested only 10-percent of the unprotected cone crop. The Bidrin® treatment reduced *Dioryctria* infestation to less than 2 percent. The net gain is seed yield per tree, as a result of controlling both *Laspeyresia* and *Dioryctria*, was 27 percent (Table 2). Assuming the seed was superior seed from a seed orchard and worth $15.00 per lb., the value of the increased seed yield would amount to $4.50 per tree. The cost of the single implant was $1.70 per tree including materials and labor.

Table 2.--Slash pine seed yields from Bidrin® implant treatments to control seedworms and coneworms, Olustee, Fla. 1967

Treatment	Average seed yield/ cone	Average yield of seed/ tree 1/	Increase seed yield/tree over checks		Value of seed/ tree 2/	Value of the increased seed yield/ tree
	Number	Lb.	Lb.	(Percent)	Dollars	
		Laspeyresia Damage Only 3/				
Bidrin® implant (5 gm./in. dia.)	83.1	1.5	0.2	(15)	22.50	3.00
Check - never treated	74.6	1.3	--	--	19.50	--
		Dioryctria and *Laspeyresia* Damage				
Bidrin® implant (5 gm./in. dia.)	81.3	1.4	0.3	(27)	21.00	4.50
Check - never treated	64.0	1.1	--	--	16.50	--

1/ Based upon an average of 250 cones/tree and assuming an average of 14,000 slash pine seed/lb.

2/ Assuming a value of $15.00/lb. of seed.

3/ Based upon a sample of 50 cones not damaged by *Dioryctria* spp./tree.

The value of the additional seed obtained as a result of controlling *Laspeyresia* and *Dioryctria* more than offset the cost of the control efforts. For several reasons I think that these examples of "what cone and seed insect control is worth" are both realistic and conservative. First, the assumed value of $15.00 per lb. of genetically superior seed is low. As genetic gains increase by repeated clone selection superior tree seed may prove to be worth considerably more. Second, in the Bidrin® implant example, the *Dioryctria* infested only 10 percent of the total second-year cone crop which I consider an unusually light infestation. In orchards where *Dioryctria* damage accounts for losses of greater magnitude, control efforts are even more important, and more economical. Third, although not taken into account in my examples, controls which protect second-year cones also afford simultaneous protection of the first-year conelet crop from *Dioryctria* attacks. Finally, in the two examples, *Dioryctria* and *Laspeyresia* were the primary insects for which control was applied. However, some methods may also give some control of other cone and seed insects, such as the seed bugs *Leptoglossus corculus* (Say) and *Tetyra bipunctata* (H. & S.) (DeBarr, 1967) which can destroy as high as 20 percent of the seed crop in slash pine orchards.

SOME FINAL CONSIDERATIONS

The same sort of thinking would be required to evaluate the economics of non-insecticidal methods of cone and seed insect control. However, insecticides will probably continue to play an important role in seed orchard management for some time to come. Therefore, it seems worthwhile to point out several ways to make cone and seed insect control with insecticides more efficient and more economical.

First, insecticides should be used only when insects are causing seed losses of economic proportions. Insecticides applied to endemic populations provide little additional seed. But, repeated applications are expensive, can cause unnecessary pollution problems, and may contribute to a build-up of insect resistance.

Secondly, when spraying a seed orchard, it costs just as much to protect a tree with half a bushel of cones, as it does one the same size with 4 bushels. The same is true for implanted systemics. Thus, the orchardist might consider protecting only the clones of high productivity, rather than every tree in the orchard. In this way most of the seed will be protected at a much lower cost.

Finally, clones vary in their inherent resistance to cone and seed insects. This was first shown for *Dioryctria* spp. (Merkel *et al.* 1965) and *Laspeyresia* spp. (Merkel 1967) on slash pine, and later for the seedbugs and flower thrips (DeBarr *et al.* 1971), as well. The orchardist might consider spraying only the most susceptible clones, or perhaps even rogueing them where spacing permits; the entomologist should look for the factors responsible for susceptibility, and the genetist should consider the merits of breeding resistance to cone and seed insects.

LITERATURE CITED

Barber, John C. 1963. How much is forest genetics helping the forester by increasing growth, form, and yield? Proc. 7th South. Tree Improv. Conf., Gulfport, Miss., pp. 16-20.

Davis, L. S. 1967. Production costs and economic potential of investments in loblolly pine clonal seed orchards. J. Forestry 65: 882-887.

DeBarr, G. L. 1967. Two new sucking insect pests of seed in southern pine seed orchards. Southeast. Forest Exp. Sta., U.S. Forest Serv. Res. Note SE-78, 3 pp.

DeBarr, G. L., and F. R. Matthews. 1971. Mist blower applications for control of flower thrips and southern cone rust in a slash pine seed orchard. J. Econ. Ent. 64: 520-522.

DeBarr, G. L., and E. P. Merkel. 1971. Mist blower spraying of longleaf pine for cone and seed insect control. U.S. Forest Serv. Res. Pap. SE-76, 7 pp.

DeBarr, G. L., E. P. Merkel, Claude H. O'Gwynn, and Marvin H. Zoerb, Jr. Phorate tests for slash pine cone insect control with observations on clonal variation in insect infestation. (Unpublished Manuscript).

Fatzinger, C. W., and G. L. DeBarr. 1969. How to distinguish attacks by the black turpentine beetle and *Dioryctria amatella* on southern pines. Southeast. Forest Exp. Sta., U.S. Forest Serv. Res. Note SE-101, 4 pp.

Marler, R. L. 1963. Economic consideration of the genetic approach. Proc. 7th South. Tree Improv. Conf., Gulfport, Miss., pp. 59-63.

Merkel, E. P. 1967. Individual slash pines differ in susceptibility to seedworm infestation. J. Forestry 65: 32-33.

Merkel, E. P., and G. L. DeBarr. 1971. Bidrin trunk implantation in slash pine seed production stands for cone insect control. J. Econ. Ent. (In press).

Merkel, E. P., and D. O. Yandle. 1965. Mist blower applications of insecticides for cone insect control on slash pine. Southeast. Forest Exp. Sta., U.S. Forest Serv. Res. Note SE-52, 4 pp.

Merkel, E. P., A. E. Squillace, and G. W. Bengtson. 1965. Evidence of inherent resistance to *Dioryctria* infestation in slash pine. Proc. 8th South. Conf. on Forest Tree Improv., Savannah, Ga., and Ga. Forest Res. Council, Macon, Ga., pp. 96-99.

Perry, Thomas O., and Chi-Wu Wang. 1958. The value of genetically superior seed. J. Forestry 56: 843-845.

Smith, R. H., and Francois Mergen. 1954. A bark beetle attacking scions of grafted slash pines. J. Forestry 52: 864-865.

USE OF TREE SPADE

Oliver W. Buckles [1]

Almost every seed orchard manager has at one time or another attempted to transplant established grafts. Some have found it convenient to move a few individual ramets while others have been forced to relocate entire orchards. Longleaf workers have often found it necessary to move 3 or 4 year old plants. Success has been quite variable.

The Francis Marion Seed Orchard, located near Moncks Corner, S.C. was established to supply genetically superior pine seed to the National Forests of the coastal plain and piedmont regions of North Carolina, South Carolina, and Georgia. When completely established, the orchard will contain some 13,000 loblolly, shortleaf, and longleaf ramets, about 4500 of which will be longleaf.

At the Francis Marion Seed Orchard, efforts have centered around mechanizing the transplanting of longleaf. After using hand tools, and a home-made lifting device, a hydraulic tree spade has now been adopted for the transplanting operation. The advantages of the spade over manual transplanting are considerable when time, materials, and eventual survival are considered. This machine does an excellent job of transplanting with a minimum of shock.

Longleaf ramets previously were established in the Francis Marion Orchard by field grafting. The 1-0 longleaf rootstock was planted 3 to each site in the orchard and grafted as soon as height growth began. Thus rootstock was usually grafted 2 to 3 years following planting. Success has generally been good with this method but field grafting is rather slow as compared to bed or bench grafting. Also, the irregularity with which longleaf rootstock begins height growth requires working over the same areas two or more times in order to complete all grafts.

If an orchard site becomes vacant because of graft failure, incompatibility, or failure of the rootstock to initiate height growth, and the adjacent sites are occupied, the vacant site should be filled as quickly as possible. Otherwise, management problems may develop when a wide age differential exits between adjoining ramets. Much time can be saved by transplanting an established graft into the vacant site. Grafts up to 6 to 8 years old can conceivably be moved with the balled transplant technique using the spade. Keithley reports that using a 40" spade they are able to move 18-20 foot loblolly with a survival in excess of 90%. Thus, depending on availability of replacement grafts, vacancies could be filled for several years longer than would be possible using field grafting methods. In addition to the time saved, management problems could be held to a minimum.

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[1] Orchard Manager, stationed at the Francis Marion Seed Orchard, which is maintained at Moncks Corner, South Carolina, by the Francis Marion and Sumter National Forest, Forest Service, U.S. Department of Agriculture.

The tree spade consists of 4 hydraulically operated steel spades mounted within a frame. The spades can be pushed into the ground under the roots to form a variety of ball sizes. When the 4 converging blades meet, the tree and ball are lifted and are ready for transplanting. The spade at the Francis Marion Orchard is mounted on the rear of a rubber-tired tractor and can dig a maximum ball size of 30 inches. Smaller ball sizes may be dug by hydraulically lifting the spade frame before digging.

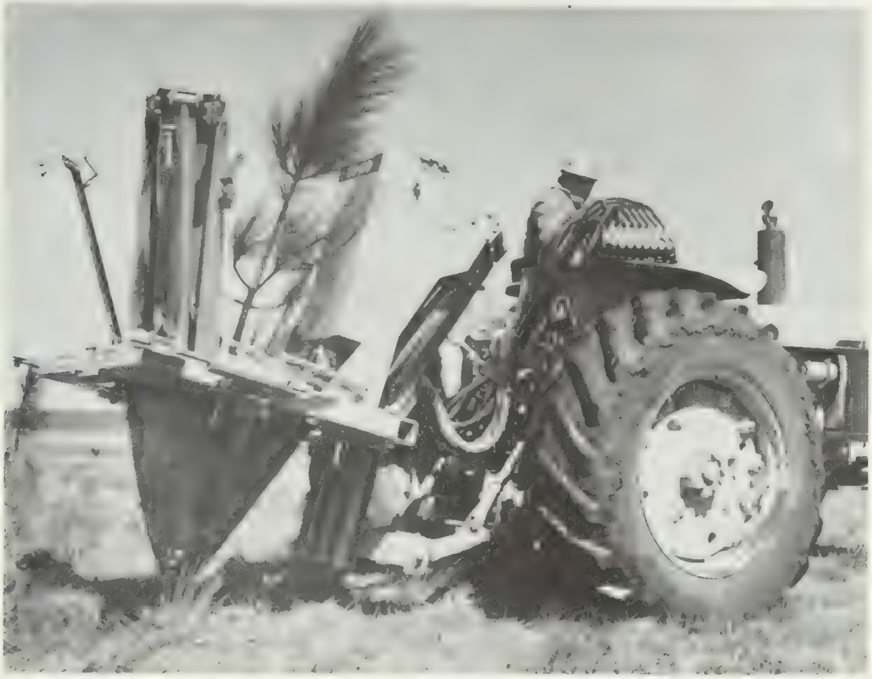

Figure 1.--A 2 year old longleaf graft being transplanted with the tree spade.

Once the tree is lifted it can either be transported to the new location in the spade or transferred to a container. Many different types of containers are available. Wooden wire-bound boxes and boxes made of heavy corrugated organic material are made to receive the cone shaped ball lifted by the spade. Contour formed burlap bags with aluminum wire baskets are available. Home-made containers can be fashioned out of woven wire or single strand wire with a burlap liner. Home-made containers are cheaper and are satisfactory where rehandling and holding in a staging area are held to a minimum. Where the grafts can be transported to the new planting site in the spade, costs of labor, equipment, and materials are held to a minimum. An operator and helper can move 45-55 plants per day at the Francis Marion Orchard where distances average $\frac{1}{4}$ to $\frac{1}{2}$ mile. Longer moving distances would require transfer to containers and hauling by truck or trailer. Ball size and weight dictate some sort of mechanical lifting device where containers are used.

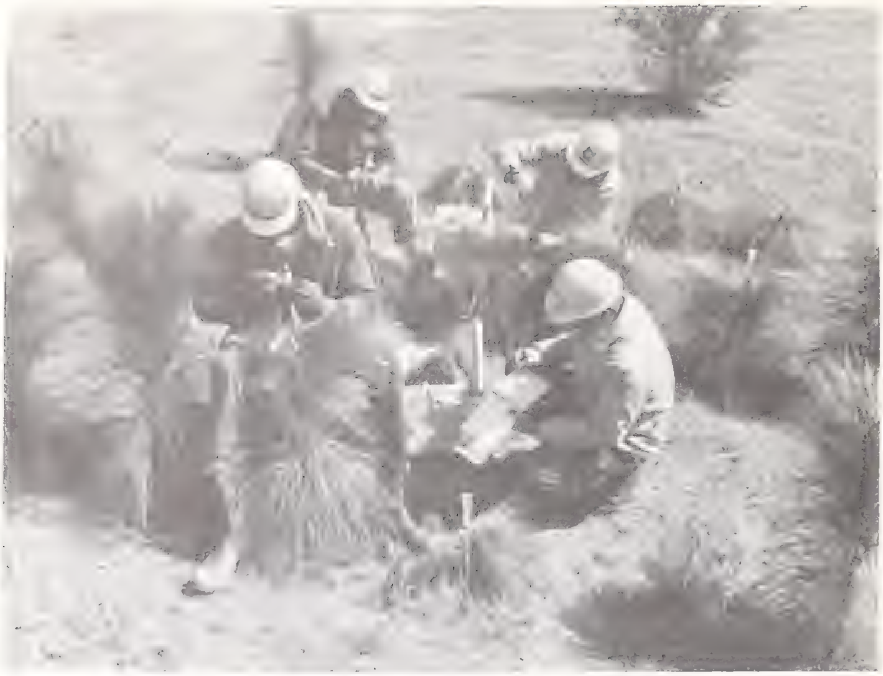

Figure 2.-- Longleaf being grafted in beds for later transplanting to permanent planting sites.

Due to the high degree of success in transplanting with the tree spade, bed grafting with subsequent transplanting to the orchard has been adopted as standard procedure for longleaf and loblolly at the Francis Marion Orchard. Rootstock is lined out in beds allowing adquate room for lifting (3' X 3'). These beds are located adjacent to the orchard to reduce transport time. Cost of rootstock production is reduced as a result of the centralized location of seedlings in a bed. The rootstock is grafted in the bed and after one growing season transplanted to permanent orchard locations. As an additional benefit, longleaf rootstock seems to come into height growth sooner in a bed than it does in the field due to more intensive cultural treatment.

At transplanting time the receiving hole for the tree is dug at the permanent planting location and the graft is then lifted and set in the predug site, paying attention to eliminate air pockets. The spade is equiped with a watering system designed to lubricate the cutting blades while lifting. Using this system, a root stimulator solution is applied to the ball to aid in recovery of the root system. The clean shearing cut of the spades does a minimum of damage to the root system and provides optimum conditions for healing and new root development.

Transplanting success is high. In moving longleaf and loblolly grafts 3-5 feet in height we have not experienced any mortality. To date, some 1025 longleaf and loblolly grafts have been moved. The increased efficiency with which one can establish an orchard, plus the ability to replace lost ramets, makes the tree spade a most valuable piece of equipment.

TRUNK IMPLANTS OF SYSTEMIC INSECTICIDES IN SEED ORCHARD SLASH PINE TREES FOR CONTROL OF THE CONEWORM, *Dioryctria* sp. (Lepidoptera: Phycitidae)

Henry W. Ray[1] and W. W. Neel[2]

Trunk implants of systemics have largely been used to control insects that attack conifers. Johnson and Rediske (1965) used Bidrin and Meta-Systox-R in trunk implants to control Douglas-Fir cone and seed insects. In a trunk implant test using Bidrin at the rate of 3.4 and 1.5 grams of active ingredient per inch of dbh Merkel (1969) found the rate of *Dioryctria* sp. infestation of 2nd-year slash pine cones was 5.0% and 3.0% respectively, as compared to an untreated control rate of 18.0%. In a similar test, Merkel (1970) reported that trunk implants of Bidrin and Meta-Systox-R effectively controlled *Dioryctria* infestations in slash pine cones.

There have been no published reports of the effects, if any, of systemic implants on the germination of seed taken from these treated trees.

MATERIALS AND METHODS

This study was conducted at the Scott Paper Company slash pine seed orchard in Greene County, Mississippi, in 1970. This orchard has had a past history of heavy coneworm, *Dioryctria* sp. attacks. The cone producing area of the

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[1] Formerly graduate assistant, Entomology Department, Mississippi State University. Presently employed by Geigy Chemical Company, Greenville, Mississippi

[2] Associate Professor, Entomology Department, Mississippi State University, State College, Mississippi.

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orchard consists of 20 acres of grafted slash pine, *Pinus elliottii* Engelmann.

Five clones, 4, 8, 16, 19, and 21, which had 10 or more cone-bearing trees were selected for this study. One of the criteria chosen for selecting a tree was the presence of at least 10 to 20 2nd-year cones. The results were based on one untreated control and 3 insecticide treatments. Each of the five clones was represented twice in each treatment, making a total of 10 trees per treatment. These test trees were all grafted in 1959, and had an average height of 25 feet and an average diameter of 8.2 inches at breast height.

All of the insecticides were tested at a dosage rate of 5 grams of actual toxicant per diameter inch of tree trunk measured at breast height. Table 1 shows the mean dosages that were applied in each treatment.

The method of trunk injection used in this study is referred to as the "drill-hole" method. With this method a carpenter's brace and bit were used to drill the holes. The injection of Azodrin and Bidrin was done with 10 ml. and 1 ml. pipettes. This rather slow method was substituted for a faster method using a 12 cc. plastic disposable syringe with Meta-Systox-R.

The total crop of 2nd-year cones was harvested in September 1970. All 2nd-year cones from each tree were sorted, counted, and the number of infested and non-infested cones recorded. A cone was considered infested when it showed an entry hole made by *Dioryctria* sp. larvae.

To compare the germination of seeds from infested and non-infested cones, a sample of 0-50 seeds was taken from infested and non-infested cones of each tree. Table 2 shows the mean sample size for each treatment. Each sample was placed in an individual water-filled petri dish. The seeds were allowed to soak for two days, and then the water was poured off. They were then put into plastic bags along with labels identifying them, and the tops of the bags were tied. These bags were placed in a refrigerator at 35°F. for 30 days.

The seed samples from each bag were placed in individual, clear plastic petri dishes which had a piece of moistened 4" by 4" blotter paper in the bottom. A pinch of Captan was added to each dish to inhibit the growth of mold. The trays holding the dishes were placed in a germination chamber at 25°C., 95% relative humidity, and 12-hour periods of light and darkness. The seeds were observed every 3 days, Table 1.--Basic information in the design of the study, including treatments, size of treatments, and insecticide rates.

Treatment	No. of trees /treatment	Date treated	Ml./ tree	Active ingredient/ tree[1]
Azodrin, 3.2 EC	10	5-7-70	110.6	42.0
Bidrin, technical	10	5-7-70	35.3	38.5
Meta-Systox-R, 2 EC	10	6-2-70	172.1	41.1
Control	10	--	--	--

[1] Measured in grams.

Table 2.--The mean number of samples of seed from infested and non-infested 2nd-year slash pine cones and the mean number of seed in samples per treatment.

Treatment	No. samples (infested)	No. samples (non-infested)	No. seed/sample (infested)	No. seed/sample (non-infested)
Azodrin	10	10	35	50
Bidrin	10	10	49	50
Meta-Systox-R	10	10	44	49
Control	10	10	48	50

whenever possible. Each time the seeds were checked, those which had germinated were removed from the dishes, counted, and the data recorded. A seed was considered germinated when its emerging root showed signs of geotropism. Water was added, if the blotter showed signs of drying. The duration of the germination test period was 30 days.

RESULTS AND DISCUSSION

All of the injected trees showed various degrees of phytotoxicity, chiefly needle browning and shedding, and scattered small limbs deadening for at least 9 months after the treatments. The Azodrin treated trees appeared more severely affected than trees in the 2 other treatment groups.

Cones were harvested in September 1970, and were sorted and tabulated as being infested or non-infested. Differences in the mean infestation rates of the cones collected from the 4 treatments were statistically analyzed. F tests showed that the variance in infestation rates of cones/treatment was highly significant as $p \leq .01$. The mean infestation rates were compared with Duncan's new multiple range test (Table 3).

Dioryctria sp. were found to cause significant losses of seed in the study trees. Some cones were damaged so badly that they failed to open, and therefore yielded no seeds. The mean differences in seed yields were analyzed and F tests showed that the differences in seed yields of infested and non-infested cones were significant at $p < .01$. The means were further tested with DNMRT, and the results are shown in Table 4.

Data, comparing the germination of seeds from infested and non-infested cones, were taken from a 30-day germination test. Table 5 shows the numbers of seeds which germinated from infested and non-infested cones when compared by treatments. The data from the seed germination tests for treatments were analyzed with a CRD. F tests showed that the differences in means of seed which germinated from non-infested cones were non-significant at $p < .05$. When compared by DNMRT the means were shown to be homogeneous. F tests performed on the germination means of the seed from the infested cones showed that the differences in means among the treatments were significant at $p < .05$. Using DNMRT the means were further analyzed and the results are shown in Table 5.

Table 3.--Total number of cones in the treatment groups, average number of infested cones per tree, and average infestation rate per treatment.

Treatment	No. sample trees	Total no. cones/tree	No. infested cones/tree	Infestation rate[1] (percent)
Azodrin	10	199.00	14.56	10.97a
Bidrin	10	131.10	25.18	20.04a
Meta-Systox-R	10	199.80	46.00	33.81 b
Control	10	159.64	48.54	39.05 b

[1] Those means that have a common small case letter arenot significantly different at the 1% level of probability as judged by Duncan's new multiple range test.

Table 4.--Seed yields from infested and non-infested cones as affected by insecticide treatments.

Treatment	Mean seed yields[1] per cone
Azodrin	55.1a
Meta-Systox-R	48.9 b
Bidrin	48.8 b
Control	39.9 c

[1] Those means that have a common small case letter are not significantly different at the 5% level of probability as judged by Duncan's new multiple range test.

Table 5.--The germination of seed from infested and non-infested cones as affected by insecticide treatments.

Treatment	% germinated[1] (non-infested cones)	% germinated[1] (infested cones)
Azodrin	43.0a	62.0a
Bidrin	43.2a	44.0 b
Meta-Systox-R	51.0a	50.2 b
Control	45.4a	49.7 b

[1] Those means that have a common small letter are not significantly different at the 5% level of probability as judged by Duncan's new multiple range test.

CONCLUSIONS

In this study the mean infestation rates of 2nd-year cones from two insecticide treatments, Azodrin and Bidrin, differed significantly at $p < .01$ from the untreated control. The mean infestation rate of cones in the Meta-Systox-R treatment did not differ significantly from the untreated control at $p < .01$.

The insecticide treatments affected the seed yields of the 2nd-year cones. The trees in the Azodrin treatment which had the lowest infestation rates per cones also had the highest seed yield per cone. The mean seed per cone yields of the Bidrin and Meta-Systox-R treatments were lower than that of the Azodrin treatment. The seed per cone means of the 3 insecticide treatments differed significantly from that of the untreated control at $p < .05$.

The differences in mean germination rates of seeds among treatments from non-infested 2nd-year slash pine cones was non-significant at $p < .05$. The differences in mean germination rates of seeds among treatments from infested cones was significant at $p < .05$. The mean germination rate of infested cones from the Azodrin treated trees was significantly different from the other two insecticide treatments and the untreated control.

Of the three treatments, Azodrin gave the best coneworm control and had the highest seed yields. Bidrin was second best, and Meta-Systox-R with considerably more cones infested, was third best.

LITERATURE CITED

Johnson, N. E. and Rediske, J. H. 1965. A test of systemic insecticides to control Douglas-fir cone and seed insects. J. Econ. Entomol. 58(10): 1020-1021.

Merkel, E. P. 1969. Control of insects in slash pine cones with trunk implantations of Bidrin systemic insecticide--First-year results. U.S. For. Ser. Res. Note S.E., No. 109.

Merkel, E. P. 1970. Trunk-implanted systemic insecticides for slash pine cone insect control. The Florida Entomologist 53(3): 143-146.

SEED ORCHARD DESIGN, THEORY AND PRACTICE

J. P. van Buijtenen[1/]

INTRODUCTION

Present seed orchard designs used in the South can be grouped roughly into three major categories--(1) the so-called "free love" orchard, (2) the randomized orchard, and (3) systematically arranged orchards. In the free love orchard, grafts are planted without any particular design and with minimum attention to close proximity of grafts of the same clone. The arrangement is especially prevalent in the older orchards. In the randomized orchard, grafts are randomized either throughout the orchard or within blocks, usually with the restriction that grafts of the same clone cannot be in close proximity to each other. The most common restriction is that two grafts of other clones have to fill the intermediate positions. A number of computer programs are available to accomplish this rather tedious job (Bastide [1967], Feret [1971], van Buijtenen [1971]). In systematically arranged orchards, a number of designs have been developed. One design calls for blocks of ten clones, which are systematically arranged as shown in Figure 1. The design was developed by Langner and Stern (1955).

A	B	C	D	E	F	G	H	I	K
H	I	K	A	B	C	D	E	F	G
E	F	G	H	I	K	A	B	C	D
B	C	D	E	F	G	H	I	K	A
I	K	A	B	C	D	E	F	G	H
F	G	H	I	K	A	B	C	D	E
C	D	E	F	G	H	I	K	A	B
K	A	B	C	D	E	F	G	H	I
G	H	I	K	A	B	C	D	E	F
D	E	F	G	H	I	K	A	B	C

Figure 1.--Systematic seed-orchard lay-out for 10-clone block according to Langner and Stern (1955).

The advantages and disadvantages of the various systems can be evaluated best by examining the objectives of seed-orchard design.

OBJECTIVES OF SEED-ORCHARD DESIGN

In current seed-orchard designs, the following objectives should be satisfied: (1) provision of as high a ratio as possible between pollen from the selected trees in the orchard and contaminating pollen from the outside; (2) provision of an adequate pollen supply throughout the orchard in order to secure a high seed set; (3) maximization of the number of combinations in which trees are crossing with each other, in order to assure maximum genetic variability; (4) minimization of the amount of inbreeding in the seed orchard.

[1/] Principal Geneticist, Texas Forest Service, and Professor, Texas A&M University, College Station, Texas.

Objectives one and two are very closely related and so are objectives three and four. At first glance it might seem that satisfying one objective would also satisfy the other. This is, however, not necessarily the case. For instance, providing a generous isolation zone might give a very favorable ratio between improved pollen and contaminating pollen, while at the same time the overall pollen supply might be inadequate. Similarly, randomization in a seed orchard would tend to increase the number of possible crosses that could occur but would not necessarily solve the inbreeding problem.

Objective 1. Provision of a Favorable Ratio of Improved to Contaminating Pollen

The accepted method for providing a favorable ratio is the creation of an isolation zone. The standard for seed certification is four hundred feet. As pointed out by Squillace (1967), this still allows a considerable amount of contaminating pollen to reach the orchard, although as shown by McElwee (1970), it is certainly of benefit. In first-generation orchards there is not much that can be done about this contamination. In advanced-generation orchards and orchards made up of clones of known characteristics, other techniques are possible. It might be particularly beneficial to designate as pollinators certain clones which are of good quality and produce large amounts of pollen.

To simplify the discussion, the non-pollinator trees will be designated as seed trees. We now have two categories of trees--seed trees, which are known to produce good seed crops but may or may not produce pollen; and pollinators, which are known to produce abundant pollen. Pollinators of low seed-producing capability are designated as Type I. Pollinators which are also good seed producers are designated as Type II. Thus the effectiveness of the isolation zone can be increased by surrounding the orchard with a solid row of pollinators. Type I pollinators could be grown in the isolation zone, while Type II pollinators could be part of the orchard itself. One would expect that the first row of pollinators would have the largest effect, with additional rows contributing less. Further studies would be needed to assess the benefit of various arrangements, but offhand it seems that 1 to 3 rows would cover the range of economically sound possibilities.

Objective 2. Provision of Adequate Pollen Throughout the Orchard

In first generation orchards not much can be done to help the situation. In orchards constituted of known clones, however, pollinators--preferably Type II--can be planted throughout the orchards in a number of different arrangements. They can be distributed randomly, they can be planted in rows, or they can be interspersed throughout the orchard in a grid-like arrangement. This last type of arrangement would insure the best distribution of pollen throughout the orchard, with the minimum number of pollinators needed. In order to keep the genetic base from becoming too narrow, it is recommended that a minimum of three pollinator clones be used and preferably more.

The design can be varied according to the number of clones available. Following are some designs that will fit a number of common situations. (1) If, out of a total of 10 clones, five pollinators are available, Langner's design could be modified by assigning a pollinator clone to alternate positions. This would result in a complete checkerboard distribution of pollinators, as shown in Figure 2. (2) If a smaller number of pollinators is available, every other tree in alternate rows could be assigned as a pollinator. Including the pollinator row at the outside of the orchard and assuming an arrangement of 31 x 31 trees, there would be 645 seed trees, 196 pollinators (preferably Type II) in the orchard and 120 pollinators (Type I or Type II) around the orchard for a total of 961 trees (Figure 3). (3) If a lesser proportion of pollinators is desired, they could be planted every third row and every third tree within the row (Figure 4). The arrangement described would result in 760 seed trees, 81 pollinators (preferably Type II) in the orchard, and 120 pollinators (Type I or Type II) around the orchard.

A̲	B	C̲	D	E̲	F	G̲	H	I̲	K
H	I̲	K	A̲	B	C̲	D	E̲	F	G̲
E̲	F	G̲	H	I̲	K	A̲	B	C̲	D
B	C̲	D	E̲	F	G̲	H	I̲	K	A̲
I̲	K	A̲	B	C̲	D	E̲	F	G̲	H
F	G̲	H	I̲	K	A̲	B	C̲	D	E̲
C̲	D	E̲	F	G̲	H	I̲	K	A̲	B
K	A̲	B	C̲	D	E̲	F	G̲	H	I̲
G̲	H	I̲	K	A̲	B	C̲	D	E̲	F
D	E̲	F	G̲	H	I̲	K	A̲	B	C̲

Figure 2.--Modification of previous design by designating alternate clones as pollinators. Underlined letters are pollinators (Type II). Others are seed trees.

Objective 3. Maximization of Cross Pollination

The most effective way to assure that the greatest number of possible crosses occurs is by complete randomization within the orchard. The picture is, however, confused by several factors. (1) Some clones produce a disproportionately large amount of seed. This effectively reduces the number of crosses that actually occur. (2) Some clones produce an excessively large amount of pollen. This further reduces the number of possible combinations that do occur. (3) Normally, at any time only a small portion of the clones are fully receptive and a small portion are shedding pollen. The flowering dates of the different clones vary, with a few clones starting early, the bulk of them being intermediate, and finally a few flowering considerably later than the majority. This, again, serves to further restrict the number of crosses among clones. These factors have a much more profound influence on the mixture of crosses produced than the physical arrangement of the clones in the orchard.

In a first-generation orchard, we have no control over these factors. In second-generation orchards we do. Every effort should be made to help the situation by balancing both seed production and pollen production among clones. Also to be examined in evaluating the effectiveness of randomized versus systematic designs are the benefits derived from a maximum number of crosses. We might approach this problem as follows. In looking at the table of all possible crosses, the ideal that we might strive for is to have all squares filled with an equal number of seeds except for the selfs, which should be completely absent. Now let us see how we are affected if part of these crosses are missing. First of all, one half is simply the

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Figure 3. Alternate trees in alternate rows are designated as pollinators. A minimum of 4 clones is needed, arranged systematically. Seed trees could be arranged either randomly or systematically. 0 = Pollinator (Type I or Type II). 1, 2, 3, 4 = Pollinator (Type II). · = Seed trees.

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Figure 4. Every third tree in every third row is designated as a pollinator. The design itself puts no limit on the number of pollinators. It is sound practice, however, to use as many pollinators as feasible, certainly not less than 4. Seed trees can be arranged either randomly or systematically. 0 = Pollinator (Type I or Type II). 1, 2, 3, 4 = Pollinator (Type II). · = Seed trees.

reciprocal of the other. Since so far no one has shown the existence of maternal effects in forest trees, one of these halves can be completely eliminated without any loss. A further reduction in number of families, but without loss of entire clones from the pool of crosses, would result in a reduction of the between-family genetic variation, but with little loss of genes from the gene pool. In other words, several combinations of genes would not be represented, but the genes would be preserved and new combinations could be created in future generations. If the reduction in the effective number of crosses were so severe that some clones for all practical purposes were not represented at all, a serious loss of genes from the gene pool would result, and remedial steps should be taken. The controlled crosses made for the purpose of progeny testing serve an essential function here. Except for random sampling variation, the average quality of the progeny would not be affected by the reduction in the number of crosses represented. In other words, one can look at the occurring crosses as a sample of all possible crosses. By chance, each sample could be above or below the average, but over a large number of orchards the fluctuations should even out. In this light we can evaluate the implications of a systematic design versus a random design. In a systematic design one would expect fewer crosses to occur, but the clones should be equally well represented in the progeny as in a random design, since the representation is determined by the relative abundance of seed and pollen. Because the flowering behavior of the trees is more important in determining which crosses do occur than the physical arrangement, the effect is expected to be slight. It will tend to result in a somewhat decreased variability but without loss of genetic material or average quality of the seed.

Objective 4. Minimization of Inbreeding

The situation here becomes complicated in a hurry. The following few simple models, however, can give us some insight into what may happen and can provide a means for experimentally determining the degree of inbreeding taking place.

A simple way to determine the degree of inbreeding in the seed from an orchard is as follows: $F = P_1 \times .5 + P_2 \times .25 + P_3 \times .125$ in which

F = the degree of inbreeding expected
P_1 = the probability of obtaining seed from selfing
P_2 = the probability of obtaining seed from full sib crosses
P_3 = the probability of obtaining seed from half sib crosses

The assumption is made that the trees used to establish the orchard are not inbred, although this could be readily taken into account if necessary.

Stern (1958) worked out the expected inbreeding in the case of several generations of selection for random mating orchards and for certain conditions of restricted mating.

Inbreeding in clonal orchards.--In a clonal orchard consisting of unrelated clones--as is normally the case in first-generation orchards--the only factor influencing the degree of inbreeding is the probability P_1 of obtaining seed from selfing.

The following factors contribute to P_1: (1) the pollen contribution from the ramet itself (A_1), (2) the pollen contribution from other members of the same clone (B_1), (3) the seed set from selfs (C_1), (4) the proportion of sound seed from selfs (D_1).

The following relation now holds:

$$P_1 = (A_1 + B_1) \times C_1 \times D_1.$$

It is easy to see this way what the relative contribution of the various factors is. A_1 can be expected to be very large compared to B_1. C_1 can be expected to be somewhat smaller than one. In other words, selfed pollen might not be as effective in pollinating as crossed pollen. D_1 is known to be much smaller than one and very variable from clone to clone, some clones being completely self sterile, which would make D_1 equal to zero, other clones being almost self fertile, making D_1 close to one.

The frequency of mutants appearing in open pollinated progenies of clones carrying marker genes can give us a good estimate of the actual magnitude of the factor P_1. Since P_1 equals the proportion of selfed seed, then $P_1 = Y_1/X_1$, in which Y_1 is the percent markers showing in open pollinated seed and X_1 is the percent markers showing in the selfed seed. For example, if in one clone one percent albinos were observed in open pollinated seed and 16% in the selfed seed, the value of P_1 is .0625 and the expected degree of inbreeding would be .03.

Inbreeding in seedling seed orchards.--In seedling seed orchards, for example, an orchard derived from n females crossed with m pollen parents, the situation is much more complicated. Selfing, crosses among full sibs and crosses among half sibs, may all occur as in the general model described earlier.

P_1 (the probability of selfing) cannot be modified readily by the design of the orchard. P_2 (probability of full sib crosses) and P_3 (probability of half sib crosses), however, can be modified strongly. If separation between half sibs by one position is considered adequate, crosses among four males and four females will satisfy this requirement if single pair-matings are made. In order to make an arrangement including all possible crosses, five males and five females are needed. A planting arrangement is presented in Figure 5. If one wants to separate half sibs by two intervening locations, the minimum number of males and females needed is nine. In the case of a 9 by 9 scheme, only a single pair-mating scheme is feasible. In the case of 10 by 10, an arrangement including 50 of the 100 crosses is feasible. To plant all possible crosses, the minimum feasible number is 11 males and 11 females. Designs are presented in Figures 6 to 8.

Aa	Bb	Cc	Dd	Ee
Dc	Ed	Ae	Ba	Cb
Be	Ca	Db	Ec	Ad
Eb	Ac	Bd	Ce	Da
Cd	De	Ea	Ab	Bc

Figure 5.--Planting arrangement for all possible crosses among 5 females (capitals) and 5 males (small letters) leaving at least one intervening position between half sibs.

Aa	Bb	Cc
Dd	Ee	Ff
Gg	Hh	Ii

Figure 6.--Planting arrangement for single pair-mating scheme among 9 females (capitals) and 9 males (small letters) leaving at least 2 intervening positions between related trees.

Aa	Bb	Cc	Dd	Ee	Ff	Gg	Hh	Ii	Kk
Hd	Ie	Kf	Ag	Bh	Ci	Dk	Ea	Fb	Gc
Eg	Fh	Gi	Hk	Ia	Kb	Ac	Bd	Ce	Df
Bk	Ca	Db	Ec	Fd	Ge	Hf	Ig	Kh	Ai
Ic	Kd	Ae	Bf	Cg	Dh	Ei	Fk	Ga	Hb
Ff	Gg	Hh	Ii	Kk	Aa	Bb	Cc	Dd	Ee
Ci	Dk	Ea	Fb	Gc	Hd	Ie	Kf	Ag	Bh
Kb	Ac	Bd	Ce	Df	Eg	Fh	Gi	Hk	Ia
Ge	Hf	Ig	Kh	Ai	Bk	Ca	Db	Ec	Fd
Dh	Ei	Fk	Ga	Hb	Ic	Kd	Ae	Bf	Cg

Figure 7.--Arrangement to separate half sibs by two intervening positions. When 10 females (capitals) and 10 different males (small letters) are used, 50 of the 100 possible crosses can be utilized.

Aa	Bb	Cc	Dd	Ee	Ff	Gg	Hh	Ii	Kk	Ll
Id	Ke	Lf	Ag	Bh	Ci	Dk	El	Fa	Gb	Hc
Fg	Gh	Hi	Ik	Kl	La	Ab	Bc	Cd	De	Ef
Ck	Dl	Ea	Fb	Gc	Hd	Ie	Kf	Lg	Ah	Bi
Lb	Ac	Bd	Ce	Df	Eg	Fh	Gi	Hk	Il	Ka
He	If	Kg	Lh	Ai	Bk	Cl	Da	Eb	Fc	Gd
Eh	Fi	Gk	Hl	Ia	Kb	Lc	Ad	Be	Cf	Dg
Bl	Ca	Db	Ec	Fd	Ge	Hf	Ig	Kh	Li	Ak
Kc	Ld	Ae	Bf	Cg	Dh	Ei	Fk	Gl	Ha	Ib
Gf	Hg	Ih	Ki	Lk	Al	Ba	Cb	Dc	Ed	Fe
Di	Ek	Fl	Ga	Hb	Ic	Kd	Le	Af	Bg	Ch

Figure 8.--If 11 females (capitals) and 11 males (small letters) are used, all 121 possible crosses can be used in the above design.

ROGUING AND THINNING OF SEED ORCHARDS

The systematic designs ordinarily will leave the distribution of clones undisturbed if a systematic thinning is done, for instance, if every other row is removed. In a randomly arranged orchard, thinning may result in an imbalance of the clones. Ordinarily no serious problem would result. There is no practical way in which an orchard can be designed to provide for true roguing, since one does not know ahead of time which clones are to be removed. As a consequence, true roguing tends to result in a somewhat uneven distribution of the trees in the orchard. If the number of clones to be removed is small in comparison to the total number of trees which need to be thinned to provide adequate spacing, the problem is not too serious. Usually, however, some holes and some clumps are unavoidable.

Giertych (1965) developed a design which provides for thinning of the orchard by a well-planned arrangement of the clones in the orchard. There is no opportunity for removal of entire clones, however, without deviating from the design.

The overriding factor in roguing a seed orchard is economics. The potential loss in seed production needs to be balanced against the expected improvement in quality. Whether a loss in seed production may result in turn depends on the spacing in the orchard and the cone production of the clones to be removed. The best solution can readily be obtained by weighting each clone according to its seed production and the percent of superiority of its seed. For example, a clone producing 100 pounds of seed annually, which is 10% better than nursery-run seed, is equal to a clone producing 200 pounds of seed, which is 5% better than nursery-run seed. Both are inferior to a clone producing 75 pounds of seed which is 20% better.

SUMMARY

Most acceptable seed-orchard designs are arranged either according to a modified randomized block design or a systematic design. Various designs were discussed according to the following four objectives:

1. Creation of a favorable ratio of improved to contaminating pollen.
2. Provision of an adequate pollen supply throughout the orchard.
3. Maximization of cross pollination.
4. Minimization of inbreeding.

Several new designs were presented which may better accomplish some of these objectives.

LITERATURE CITED

Bastide, J. G. A. La. 1967. A computer program for the lay-outs of seed orchards. Euphytica 16:321-323.

Feret, P. 1971. Personal communication. Program developed at the School of Forestry, Syracuse, N.Y.

Giertych, M. M. 1965. Systematic lay-outs for seed orchards. Silvae Genetica. 91-94.

Langer, W., and K. Stern. 1955. Versuchstechnische Probleme bei der Anlage von Klonplantagen. (Problems of experimental technique in the lay-out of clone orchards). Z. Forstgenet. 4(3):81-8.

McElwee, R. L. 1970. Radioactive tracer techniques for pine pollen flight studies and an analysis of short-range pollen behavior. Ph.D. Thesis, N.C. State Univ., Raleigh. 97 pp.

Squillace, A. E. 1967. Effectiveness of 400-foot isolation around a slash pine seed orchard. Jour. Forestry 65(11):823-824.

Stern, V. K. 1958. Der Inzuchtgrad in Nachkommenschaften von Samenplantagen. Silvae Genetica. 37-42.

van Buijtenen, J. P. 1971. Unpublished. Program developed at the Forest Genetics Laboratory, College Station, Texas.

TREE GRADING WITHOUT THE USE OF CHECK TREES

J.F. Robinson and J.P. van Buijtenen [1]

INTRODUCTION

A first step in any tree-improvement program is to locate and evaluate individuals to be included in an orchard or breeding system. In forestry in the Southeast, first-generation selections from wild stands or plantations still comprise the majority of selected trees, although second-generation selections are gradually becoming more numerous.

The problem of locating suitable stands from which select candidates can be found is one with which we are all faced. In the Western Gulf Tree Improvement Region many forest landowners have practiced individual tree-selection silviculture for many years. Thus the ideal evenaged dense pure pine stands so desirable for individual superior-tree selections are scarce. The problem of selecting representative check trees in partly cut stands can be quite difficult. Selecting from such stands increases the chance of rejection of some possibly excellent trees, or conversely, the inclusion of some poor trees.

For quite some time the Western Gulf Forest Tree Improvement Program has been interested in the technique used by Goddard and Strickland at the University of Florida for evaluating trees on a common scale. After over a year of grading trees, enough data has been accumulated to apply that technique. [2]

The objective of this paper is to apply the technique to WGFTIP check-tree data in order to develop specific regression formulas to be used for evaluating trees without relying on a 5-check-tree system.

GRADING STANDARDS AT THE UNIVERSITY OF FLORIDA

In developing their grading standards at the University of Florida, Goddard and Strickland have measured a large number of dominant and co-dominant check trees from throughout Florida and South Georgia. They have applied multiple regressions to these data, plotting volume over site index, tree age, and crown size. Thus they have developed formulae for measuring a candidate tree against the average value of check trees growing under similar conditions. With the resulting equations, expected tree volumes can be calculated for given crown measurements, site indexes, and ages. Volume of a candidate tree is then compared to the expected volume of an average tree growing under similar conditions. Dividing by the standard error of regression, they get "Growth-Efficiency Units," which they use to evaluate their trees.

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[1] The senior author is WGFTIP Geneticist, the co-author is Principal Geneticist, Texas Forest Service and Professor, Texas A&M University, College Station, Texas.

[2] Goddard, R.E. and R.K. Strickland. 1969. Manual of procedures used in the University of Florida Cooperative Forest Genetic Research Program. Limited Distribution.

WGFTIP GRADING STANDARDS

As in several other grading systems, the select tree candidate is compared to five check trees growing on the same site. Checks are chosen mostly from the best dominants around the select tree; however, some codominants may also be included. The candidate tree is compared to the average of the five check trees, with percent of superiority weighted in various categories. The form characteristics of straightness, pruning, branch angle, and branch diameter are evaluated along with the volume. In general, volume is weighted more heavily than in several other systems (van Buijtenen, 1969). Growth efficiency is also evaluated by "Crown Index," which is the ratio of crown diameter to DBH, and by "Dry Matter Index," which is an adaptation of the work on growth efficiency by Brown and Goddard (1961) but which includes specific gravity in recognition of its effect on actual fiber production. Specific gravity is separately rated as a quality characteristic.

THE APPLICATION OF MULTIPLE REGRESSION TO WGFTIP DATA

The WGFTIP select tree candidates have been measured against the best dominants and codominants around them. Thus the technique used by Goddard and Strickland could be applied to WGFTIP tree-grading data. The five check trees were used to estimate site index (Schumacher and Coile, 1960) at each select tree site. All the loblolly check trees measured throughout the WGFTIP region were pooled. Data were segregated by site index, crown radius, crown length, and tree age. Multiple regression formulae were computed (Snedecor and Cochran, 1967) using volume as the dependent variable. Volumes were derived from tables developed by the Texas Forest Service.

Errors due to genetic variation in height among stands are still confounded by site differences in the regression formulae because site index is still estimated from trees measured in each stand. Thus genetic differences in height due to stands are still considered as environmental error. However, other differences are averaged over all sampled check trees, which should reduce bias due to estimates based on a non-representative, five-check-tree sample.

RESULTS AND DISCUSSION

Results

Multiple regressions were developed for all data and then segregated by age classes and site indexes, as shown in Table 1. The regression formulae developed are based solely on the accumulated sample check trees used in the Western Gulf Forest Tree Improvement Program. They represent the best trees the sampled stands have produced under given conditions of site index, age, and crown size.

Table 1.--Regression equations for volume as dependent variable against age, crown radius, site index, crown length as independent variables for loblolly pine from Arkansas, Louisiana, Mississippi, Oklahoma, and Texas

Age	Site Index	No. Trees	Equation	R^2	Standard Deviation from Predicted Volume
25-50	70-95	147	Vol.= -112.93 + 1.361 (Age) + 2.208 (Crown Radius) + 0.60 (Site Index) + 0.583 (Crown Length)	.652	± 10.33 cu. ft.
	96-124	171	Vol.= -157.75 + 1.553 (Age) + 2.683 (Crown Radius) + 1.155 (Site Index)	.619	± 13.38 cu. ft.
51-80	70-95 (78-95) actual	158	Vol.= -89.19 + 0.687 (Age) + 2.548 (Crown Radius) + 0.729 (Site Index) + 0.368 (Crown Length)	.458	± 11.15 cu. ft.
	96-124 (96-110) actual	99	Vol.= -241.85 + 1.514 (Age) + 3.022 (Crown Radius) + 1.648 (Site Index) + 0.594 (Crown Length)	.666	± 13.58 cu. ft.
Total of all categories					
25-80	70-124	575	Vol.= -135.37 + 1.034 (Age) + 2.739 (Crown Radius) + 0.985 (Site Index) + 0.419 (Crown Length)	.699	± 12.68 cu. ft.

If the appropriate formula is used, the values derived from these regression equations will indicate the expected volume of average check trees under given values of site index, age, and crown size. Age and average height of the stand must be determined in the field.

Reliability

The R^2 values in Table 1 indicate how much variation is explained by the regression formulae. In the case of trees 25 to 50 years old growing on both high and low sites, the R^2 values of .652 and .619 respectively are fairly high and predictions are reasonably reliable. So, too, in the case of trees 51-80 years old on high sites and for the formula for all categories. However the lower R^2 values of .458 for trees 51-80 years old on low sites (70-95) indicate that this regression formula should be regarded as not too precise.

Application

The check trees are measured for height and age to determine the height superiority of the selected tree and to estimate the site index. Form values such as straightness, pruning, branch angle, and branch diameter are in comparison to the stand average. In order to use the regression technique, the present WGFTIP standards could be adapted as follows:

1. Scores for height and form (straightness, pruning, branch angle, and branch diameter) would require no change in grading methods except that the selected trees would be evaluated against the stand average rather than against five check trees.

2. "Crown Index" would be eliminated because adjustments have been made in the regression formulae for differences in crown size. "Dry Matter Index" would have to be re-calculated, using the "growth-efficiency unit" in the calculation. At present

$$\text{Dry-matter index} = \frac{\text{10-year basal-area increase x specific gravity}}{\text{crown length x crown diameter.}}$$

Again, by regression, adjustments have been made for differences in crown size. The denominator is no longer necessary. A suggested change would be:

$$\text{Dry-matter index} = \begin{array}{c}\text{10-year basal-area increase x specific gravity x} \\ \text{"growth-efficiency units"}\end{array}$$

With these adjustments, the problem remaining is what weights to place on the various scores. Presently WGFTIP weights form qualities 1/3, volume qualities 1/3, and efficiency 1/3 of a total score potential close to 60 points. Rarely if ever will this 60-point potential be achieved, as most accepted trees score between 25 and 35 points.

To equalize "growth efficiency," "dry-matter index" and form qualities, each should be worth a maximum of approximately 20 points. Maximum values of "growth efficiency" will be between 2.5 and 3 standard units. Assigned values as follows will accomplish equalization:

Growth-efficiency units	0	1	1.5	2	2.5	3
Assigned values	0	4	8	12	16	20

Dry-matter index values can be weighted by multiplying by a factor of 4, as these maximum values approximate 5.

CONCLUSIONS

In practice, the best application for WGFTIP may be a compromise. In tight stands, the original grading method is probably as good as or better than the regression method. In partly cut variable stands, the regression method is probably best. The low R^2 value (.458) for regressions of older trees on lower sites indicates that a good deal of error is still to be expected in this category. As more trees are graded, site-class and age-class categories can be more restrictive, which should help to reduce error variance and increase the precision of the regression formulae.

The most promising application of the regression method is in stands of low density and high variability, where selection of check trees is difficult. In these stands, the regression formula provides a means of evaluating a candidate against a calculated standard. This standard should be reasonably consistent, as it is based on a large number of trees.

LITERATURE CITED

Brown, C.L., and R.E. Goddard. 1961. Silvical considerations in the selection of plus genotypes. J. For. 59'. 420-426.

Schumacher, F.X., and T.S. Coile. 1970. Growth and yields of natural stands of the southern pines. Durham, N.C.: T.S. Coile, Inc.

Snedecor, G.W., and W.G. Cochran. 1967. Statistical methods. Ames Iowa: Iowa Univ. Press.

van Buijtenen, J.P. 1966. Progress and problems in forest tree selection. Tenth South. Conf. on Forest Tree Improvement. Proceedings: 17-26.

GEOGRAPHIC RACES OF SHORTLEAF PINE NOT REPRODUCTIVELY ISOLATED IN A MIXED PLANTATION

Ronald C. Schmidtling[1]

Abstract.--In a shortleaf pine (*Pinus echinata* Mill.) plantation in Mississippi, western sources of the species shed pollen earlier than eastern sources. Introgression with loblolly (*P. taeda* L.) in the western sources is proposed as an explanation. Overlap in time of shedding indicated that no source was reproductively isolated from any other.

Grafting shortleaf scions onto slash rootstocks did not influence the time of pollen shedding.

Intraspecific crossing of southern pines from widely separated locations may produce desirable progeny (Zobel and McElwee 1964), but such a procedure is impractical without synchronized reproductive phenology. Described here is a study of geographic variation in reproductive phenology in shortleaf pine. Since shortleaf scions are sometimes grafted onto slash pine rootstocks in seed orchards, the effect of such grafting on reproductive phenology also was measured.

MATERIALS AND METHODS

Pollen shedding of individual trees was observed in two shortleaf pine plantations on the Harrison Experimental Forest in southern Mississippi; one is a seed source planting and the other a grafted planting.

The first, established in January 1958, contains trees from 16 sources representing most of the range of the species. The seeds were originally collected for the southwide pine seed source study in 1955. Trees were planted in a randomized complete block design with four replications of 25-tree row plots. Spacing was 8 feet between rows and 6 feet within rows. The site was cut-over longleaf land that was burned before planting. No additional cultural treatment was carried out until the end of the ninth growing season, when scattered brush and longleaf volunteers were removed.

After 10 years in the field, the trees averaged 19 feet in height and severe crown competition necessitated thinning. Approximately 50 percent of the stems were removed, mainly on a mechanical basis.

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[1] The author is Associate Plant Geneticist at the Institute of Forest Genetics, Southern Forest Experiment Station, USDA Forest Service, Gulfport, Mississippi.

Some female flowering had been noted as early as the fifth year, and beginning with the sixth year (1964) moderate numbers of female strobili were present. By 1969, a large proportion of the trees were also bearing male strobili.

The grafted planting included some of the same shortleaf geographic sources as the other planting. Scions from 1-0 seedlings from six seed sources were grafted on 1-0 shortleaf and slash pine rootstocks, and the resulting trees were planted in 1963 in single-tree plots at 11- x 11-foot spacing in a randomized complete block design of 10 replications. This plantation was fertilized initially and mowed periodically to control competition. By 1969 the trees averaged 22 feet tall and a large proportion were bearing male and female strobili.

The seed source plantation was scored for the presence of pollen in 1969 and 1970 and the grafted plantation was scored in 1970. As pollen dispersal began, those trees having pollen catkins were scored three times a week for shedding by striking the tree with a mallet. The mean start and mean end of pollen shedding were calculated for each source, and also a median date, which presumably is close to the peak shedding time for the source.

The proportion of trees flowering on each plot in the seed source plantation was normalized by arc-sine transformation, and the source means were compared by analysis of variance. Relations of proportion of each source bearing male strobili and median time of pollen shedding to latitude, longitude, and average annual temperature at the seed source were explored with linear correlations. Probability levels of 0.05 or less were considered statistically significant.

RESULTS

Fruitfulness.--The proportion of trees with pollen varied significantly by year and by seed source in the source planting (table 1). In 1969, 37 percent of the trees had pollen, as compared with only 14 percent in 1970. Individual sources varied from 77 percent for Stone County, Arkansas, in 1969 to less than 2 percent for the Alabama source in 1970. The year x source interaction was not significant.

The year x individual tree interaction was also very small. Of the 114 trees shedding in 1970, only six had not shed in 1969. Thus, pollen bearing trees could be predicted from past performance with a fair degree of accuracy.

The correlation between proportion of trees with pollen and latitude of seed source was significant but not strong, and neither the correlation with longitude nor mean annual temperature at the seed source was significant.

Table 1.--Pollen production in a shortleaf pine seed source planting in southern Mississippi

	Seed source locational data				Trees with pollen	
State	County	Latitude	Longitude	Elevation	1969	1970
		°N	°W	Feet	Percent	
Oklahoma (1)	Pushmataha	34.5	95.2	850	36	16
Texas	Cherokee	31.5	95.1	600	47	9
Oklahoma (2)	McCurtain	34.1	94.5	550	40	8
Arkansas (1)	Stone	35.5	92.3	925	77	37
Arkansas (2)	Ashley	33.0	91.9	175	40	11
Louisiana	St. Helena	30.5	90.7	60	28	18
Missouri	Dent	37.5	90.1	1250	41	20
Alabama	Tallapoosa	33.0	85.8	500	33	2
Georgia (3)	Webster	32.0	84.6	528	31	6
Tennessee	Anderson	36.2	84.1	1000	36	10
Georgia (2)	Putnam	33.4	83.5	800	20	7
Georgia (1)	Clark	33.5	83.1	700	23	4
S. Carolina	Union	34.8	81.7	500	24	2
Pennsylvania	Franklin	39.9	77.6	930	24	18
Virginia	Southampton	36.6	77.0	18	36	20
New Jersey	Burlington	39.9	74.6	105	76	52

Timing.--Pollen was shed at approximately the same time in both 1969 and 1970, and there was good agreement in individual trees as to time of shedding, i.e., trees that were late in 1969 were late in 1970, and those that were early in 1969 were early in 1970 (r = 0.827). Duration of shedding from individual trees varied from a maximum of 17 days to a minimum of 2 days, and appeared to be related primarily to the quantity of pollen catkins on the tree. In 1970 there were not only fewer trees with pollen, but crops from individual trees were lighter than in 1969. Primarily because of the light crop, the average duration of pollen shedding averaged only 6 days per tree in 1970 as compared to 8 days per tree in 1969.

There was not much difference between sources in time of pollen shedding (fig. 1). Considerable overlap was found between the earliest and latest sources, although the eastern sources began shedding a few days later than the western sources ($r_{time/longitude} = -0.904$). There was also a lesser trend for the northern sources to shed pollen later than the southern sources ($r_{time/latitude} = 0.578$).

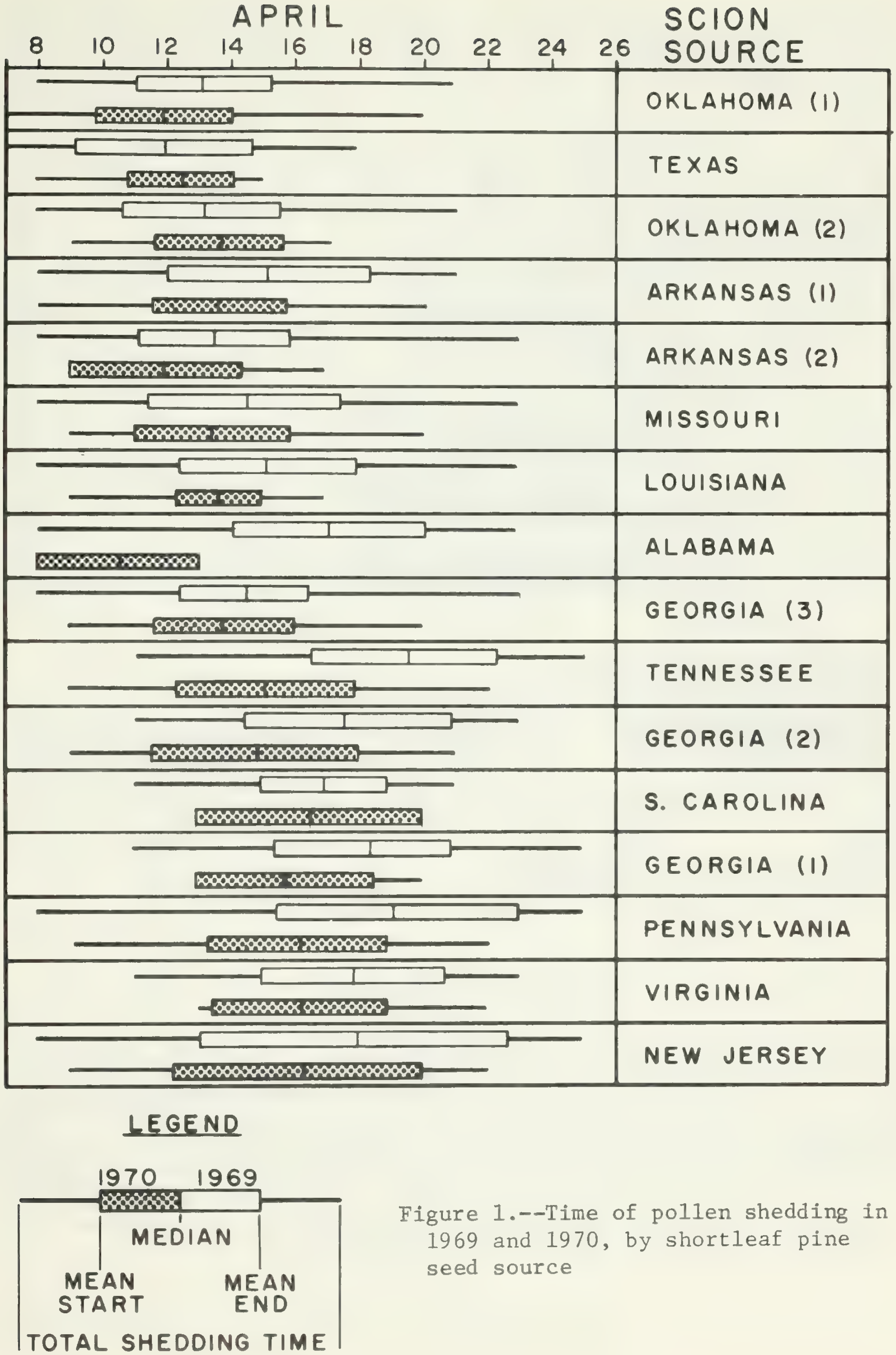

Figure 1.--Time of pollen shedding in 1969 and 1970, by shortleaf pine seed source

Rootstock/scion effects.--Scions from eastern sources also tended to flower later than western sources in the grafted planting (fig. 2). Grafting shortleaf scions on slash rootstocks had little or no effect on the time of pollen shed.

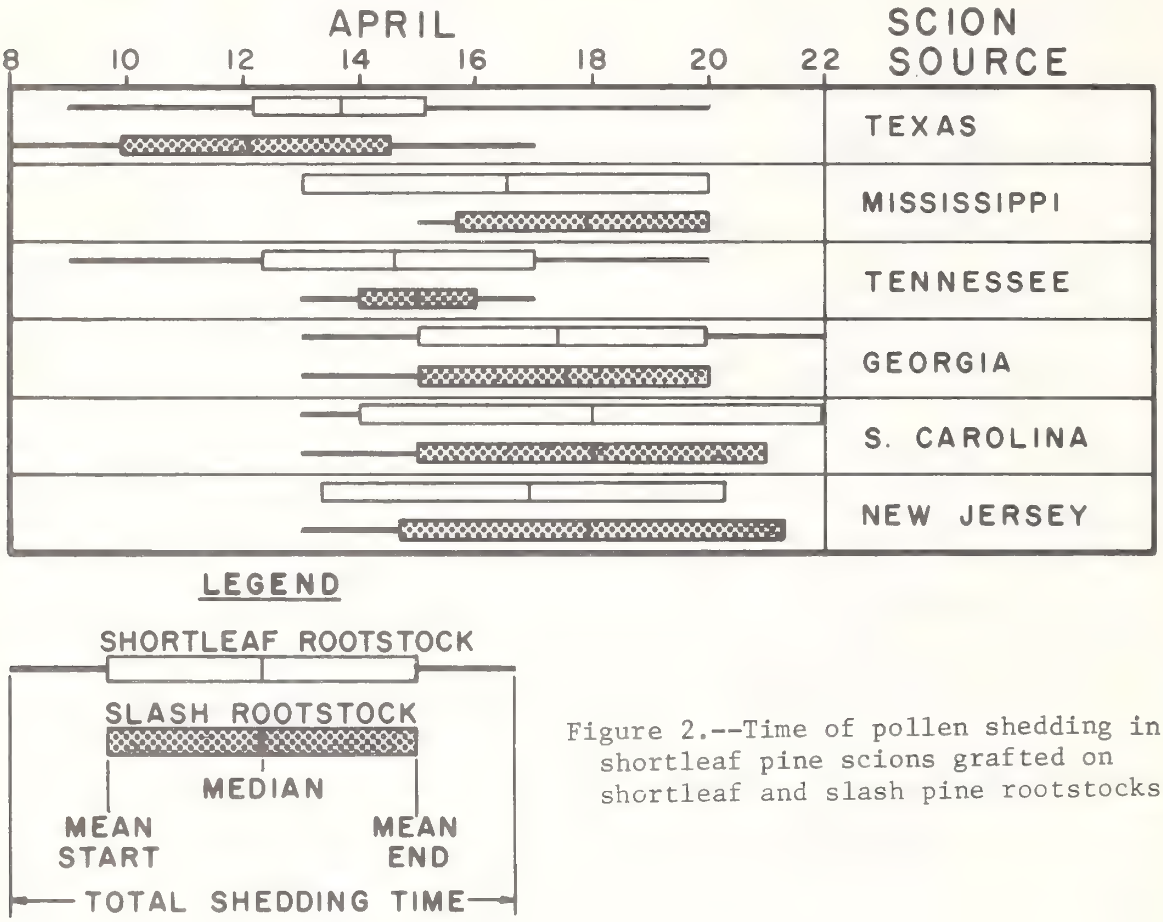

Figure 2.--Time of pollen shedding in shortleaf pine scions grafted on shortleaf and slash pine rootstocks.

DISCUSSION AND CONCLUSIONS

The close correlation of pollen shedding time with longitude is difficult to explain by climatic factors. Wells and Wakeley (1970) found that geographic variations in growth and precocity of flowering were related to the mean temperature at the seed source, which is closely related to latitude. They speculated that exceptions to this relationship could be explained by hybridization with loblolly pine in the western sources. That explanation may also apply in the present study. Loblolly pine sheds pollen earlier than shortleaf, and hybridization with loblolly at the western edge of the shortleaf range would cause pollen to be shed earlier.

The weak but significant correlation coefficient between timing and latitude of the source may be explained by a correlation between latitude and longitude ($r = -0.589$) within shortleaf's range; the species is distributed more or less along a southwest-northeast axis. If longitude is held constant by means of partial correlation, the correlation between latitude and timing becomes non-significant, whereas if latitude is held constant, the correlation between longitude and timing is not changed greatly: ($r_{\text{time/longitude}\cdot\text{latitude}} = -0.854$).

The variation observed in reproductive phenology in geographic sources of shortleaf pine does not appear to be large enough to prevent natural pollination between distant sources in mixed plantations. There was considerable overlap between sources and it appears that individual tree variation within sources is as great as variation between sources.

Ahlgren (1970) found that rootstock affected reproductive phenology in several northern species of pines. Rootstock has also been shown to influence growth (Allen 1967, 1969) and female strobilus production (Schmidtling 1969) in shortleaf pines, but it appears that grafting shortleaf on slash rootstocks has little effect on pollen phenology. Shortleaf scions have been grafted on slash rootstocks because of fast initial growth, and it does not appear that such practice will affect the timing of reproductive events.

LITERATURE CITED

Ahlgren, C. M. 1970. Inter- and intraspecific grafting and breeding of five-needle pines. Ninth Lake States Forest Tree Improv. Conf. Proc. USDA Forest Serv. Res. Pap. NC-47: 23-24.

Allen, R. M. 1967. Influence of the root system on height growth of three southern pines. Forest Sci. 13: 253-257.

__________. 1969. Contributions of tops and roots to variation in height growth of geographic sources of shortleaf pine. Silvae Genet. 18: 38-39.

Schmidtling, R. C. 1969. Influence of rootstock on flowering in shortleaf pine. Tenth South. Conf. Forest Tree Improv. Proc.: 229-230.

Wells, O. O., and Wakeley, P. C. 1970. Variation in shortleaf pine from several geographic sources. Forest Sci. 16: 415-423.

Zobel, B., and McElwee, R. L. 1964. Seed orchards for the production of genetically improved seed. Silvae Genet. 13: 4-11.

POLLEN MANAGEMENT IN SOUTHERN SEED ORCHARDS

E. C. Franklin [1]

Many of our southern seed orchards have been plagued in recent years by poor cone crops and disappointingly low yields of viable seeds. Greatly increased emphasis on pollen management in the orchards may offer solutions to seed yield and quality problems, and also provide increased genetic gains through increased selection differentials on the paternal side of the pedigree. The degree of sophistication in pollen management can vary from complete control with artificial pollination, to nothing more than an unimproved isolation zone around the orchard. While the latter may be sufficient in some orchards, additional efforts should prove to be economically sound in many cases. Therefore, a review of problems such as pollen contamination, non-synchronous flowering, and natural selfing, and a realistic appraisal of benefits to be gained from improved pollen management is needed.

DEFINING THE PROBLEMS

One of the first problems that deserves consideration is that we have very sketchy data as a basis for comparison of yields among orchards. A standardized monitoring system could supply the necessary yield information to indicate which orchards are consistently having problems. Low yields in terms of bushels of cones per acre of orchard, percentage of filled seed, and percentage of germinable filled seed have all been observed. The nature of the problem for a specific orchard can often be recognized by identifying the point where yields fall off most drastically.

For example, it has been shown for most pine species that selfing will not reduce cone yields but will drastically reduce percentage of filled seed, and substantially reduce germination percentage (Franklin, 1970). The low yields of seedlings per acre of orchard, characteristic of many orchards in recent years, has been the result of not one but many causal factors. Age and geographic origin of ortets or seedlings, lack of insect control, lack of fertilization, lack of irrigation or improper irrigation, poor cone collection and seed extraction practices, and lastly, the subject of this discussion, lack of pollen management.

The idea of pollen management in our orchards is not new. Virtually all orchards have pollen dilution (isolation) zones, and most orchards are designed to have maximum distance between ramets of the same clone, or between siblings. These practices are necessary and helpful but they are in many cases not sufficient to prevent contamination by foreign pollen or high-levels of self-pollination. The reasons are these. Whereas only 5 percent of the pollen from a point source will travel as far as 400 feet, many point sources, each contributing a small percentage of its pollen to the total pollen load, will yield a high background count of pollen almost anywhere in the vicinity of the species range. This is why "dilution zone" is a more appropriate term than "isolation zone". If the orchard produced no pollen at all, the background load would give adequate pollination in most cases for normal seed yields (Squillace 1967). Genetic gain for such a seed crop would be about half of that obtained if orchard pollen were totally effective. Non-synchronous flowering of different clones in the orchard would have a similar effect, but to a lesser extent. With non-synchronous flowering, the background contribution to the average pollen load in the orchard at any particular time would be proportionally more than if flowering were perfectly synchronous.

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[1] The author is Principal Plant Geneticist, Naval Stores and Timber Production Laboratory, Southeastern Forest Experiment Station, Olustee, Florida.

Maximum distance between ramets of the same clone or among siblings will minimize inbreeding between orchard trees, but will have no effect on frequency of selfing within the crown of each tree. The important factor within the crown seems to be the proximity of conelets and catkins. Thus in a young tree, where conelets are borne near the top and catkins near the bottom of the crown, selfing will be minimal. The typical result of crown development in orchard trees is that the mid-crown becomes an area of intimate association of conelets and catkins. The typical result is a tremendous increase in self-pollination in the lower and mid-crown areas, and a corresponding drop in percentage of filled seed as indicated by results from a single, large-crowned slash pine in Alachua County, Florida (figure 1). Corresponding increases in

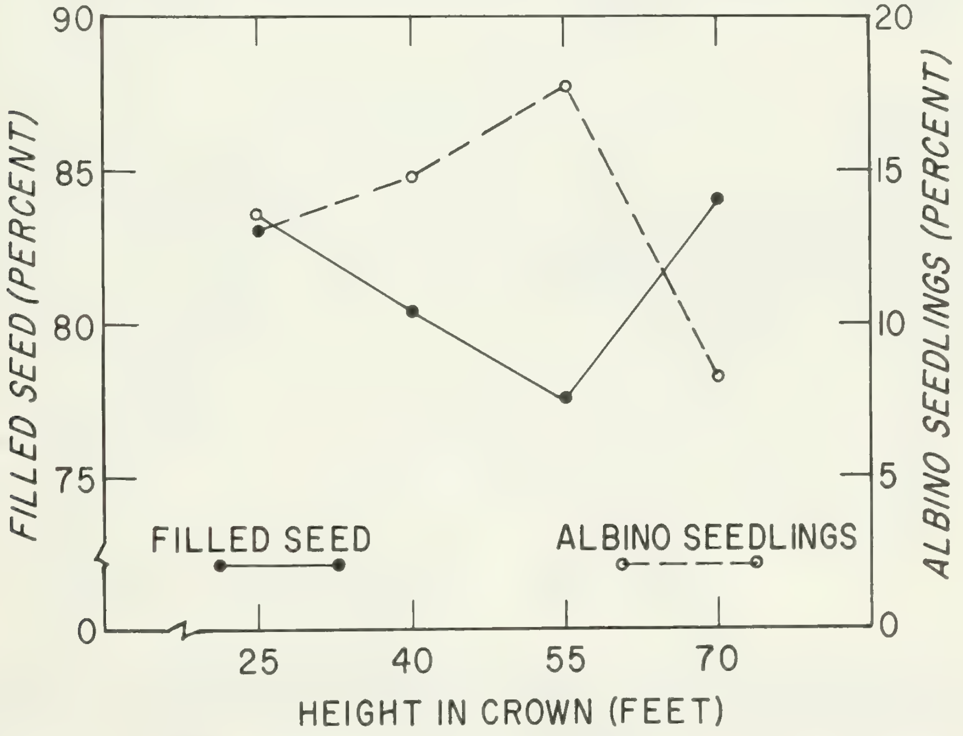

Figure 1.--Percentages of filled seed and albino seedlings by seedlots from various heights in the crown of a slash pine tree in Alachua County, Florida.

frequency of albino seedlings confirm that this is indeed the result of natural selfing. Similar results for frequency of natural self-fertilization within the crown have been found for loblolly pine (Franklin, in press). This illustration may explain in part the observation that seed yields in many orchards start out at satisfactory levels for the age of the orchard but then show a relative decrease with increasing age of the orchard.

A demonstration of the amount of self-fertilization in seed orchards is provided by an experiment recently conducted by our laboratory with the assistance of Dr. John Kraus [2]. Three ramets of each of 5 clones in the Arrowhead Seed Orchard [3] were control-pollinated using self-pollen and a 20-tree-mix from the vicinity of Olustee, Florida. Orchard open-pollinated cones were also collected. In each clone, the percentage of filled seed was less for orchard open-pollination than for controlled crossing (figure 2). Percentages of self-fertilization were estimated by the following relationship: $\frac{c-w}{c-s} \times 100$, where c, w, and s are proportions of filled seed after controlled cross-, orchard open-, and controlled self-pollination. Estimated percentages

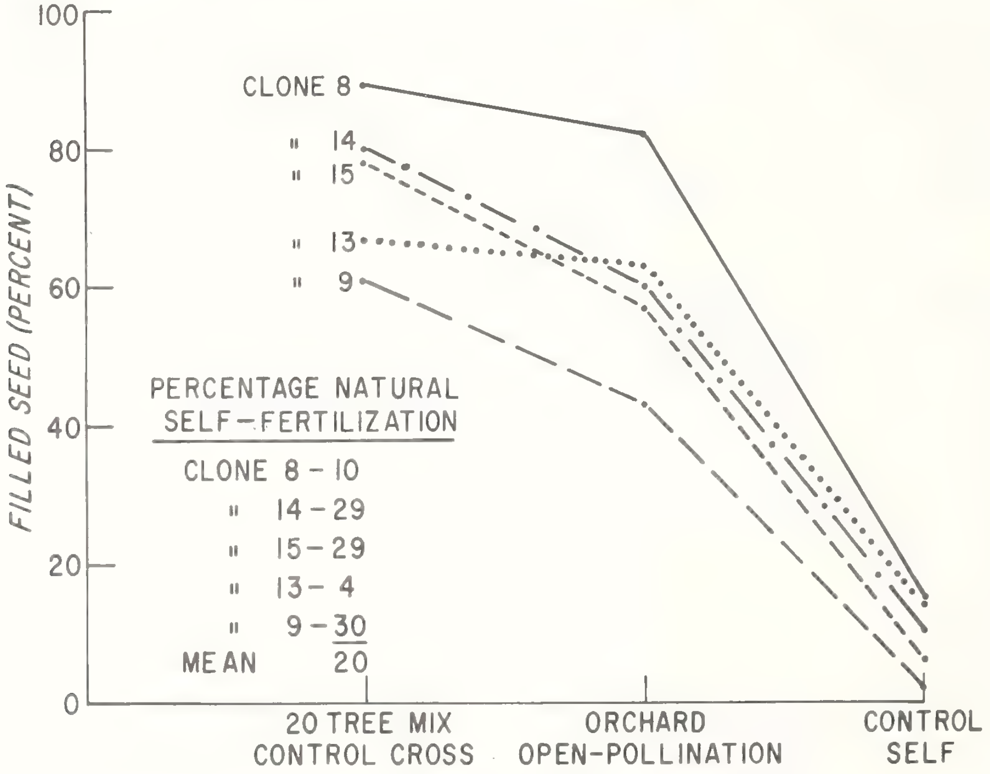

Figure 2.--Percentages of filled seed obtained from controlled selfing and crossing and orchard open-pollination from 5 clones in the Arrowhead Seed Orchard, Wheeler County, Georgia.

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[2] Principal Plant Geneticist, Southeast. Forest Exp. Sta., Macon, Ga.

[3] Georgia Forestry Commission, Wheeler Co., Ga.

of natural self-fertilization ranged from 4 to 30 percent and averaged 20 percent.

To summarize the problems, inadequate amounts of orchard pollen will reduce the genetic quality of the seed crop, and an abundance of orchard pollen will result in much self-fertilization within ramets with well developed crowns. Thus the problems involve both amount and distribution of orchard pollen in time and over areas.

SEEKING SOLUTIONS

Supplemental pollination of southern seed orchards may prove to be a profitable step toward more seed of better quality and greater genetic improvement in commercial stands. In the tree improvement program in the Republic of South Africa, hand pollination of unisolated conelets has been done for several years (Sijde, van der 1970). It has been conclusively demonstrated that hand pollination more than doubled the yield of filled seeds compared to orchard open-pollination, even with abundant pollen production in the orchard (Denison, 1971). The impact of this can be seen in yields of seed from loblolly and slash orchards in South Africa 4/.

In the 1970 seed year, unbent, hand-pollinated *Pinus elliottii* clones were 10-years-old and yielded about 40 pounds of seed per acre. Similarly, on the basis of conelets counts, unbent, hand-pollinated *P. taeda* clones in the tenth seed year are expected to yield about 150 pounds of seed per acre. Spacing for both species is 27' x 27', and germination averages 80 percent of 80 seeds per cone.

Of course, hand-pollination would not be feasible for southern seed orchards because of high labor costs. But pollen delivery systems involving agricultural dusting equipment, mist blowers, etc., could be perfected. Other technological problems involving collection, extraction and storage must be considered. Pollen produced in the seed orchard could be used advantageously for several reasons: (1) it would be easy to collect, (2) its removal would reduce natural self-pollination, (3) it is of improved genetic quality.

With a supplemental pollination system, pollen becomes an expensive and scarce commodity. Therefore, quality, principally percentage germination, becomes very important with respect to efficient use of pollen. If pollen has higher viability than necessary for effective seed set, it should be diluted with pollen of insufficient germinability, or with suitable foreign substances.

4/ Special thanks are expressed to Mr. N. P. Denison, South African Forest Investments Limited, and to Mr. S. F. Hagedorn, D. R. de Wet Forest Research Station, both of Sabie, Transvaal, Republic of South Africa, for graciously supplying the latest information on their seed orchard yields.

Application of the pollen in the orchard must be timely; i.e. supplemental pollen, if it is to be maximally effective, must reach the conelet in advance of ambient pollen. This was illustrated in a recent experiment involving a slash pine tree which is heterozygous for albinism, and gives very high yields of filled seed after selfing. Fifty isolation bags were selfed and fifty others were crossed. At the same time, 10 of the previously selfed bags received cross pollen and 10 of the previously crossed bags received self pollen. One day later, 10 more selfed bags received cross pollen and 10 more crossed bags received self pollen. A similar pattern was followed after 2, 3, and 5 days. Results averaged for all time intervals showed that 73 percent of the fertilizations were effected by the pollen first introduced into the bag. This illustrates the hypothesized "first come, first served" principle with respect to pollination and fertilization. It also indicates that non-isolated flowers could be effectively pollinated if the supplemental pollen were supplied in advance of ambient pollen. The effect of time interval between the first and second pollen received was not conclusively apparent; therefore, the experiment is being repeated.

A second question which must be answered experimentally is "what is the earliest stage of development at which a conelet can be effectively pollinated?". This cannot be determined with the use of isolation bags and will therefore require the use of genetic markers. We hope to be able to attempt to answer this question in the near future.

BENEFITS TO BE DERIVED

Benefits to be derived by supplemental pollination have already been enumerated (Sijde, van der 1970). As indicatd above, supplemental pollination assures adequate cross-pollination with pollen of improved genetic quality. Therefore, seed yields and seed quality are enhanced as evidenced by the results in the Republic of South Africa. Furthermore, increased selection pressure could be applied by using only the best parents as pollen sources. This principle is very effectively applied in many agronomic breeding programs, and can be applied in forest tree breeding as well. Another advantage related to the last mentioned one, is that genetically tailored seed crops could be produced. This would mean that male parents with high combining ability for fusiform rust resistance, high specific gravity, high salt tolerance, etc. could be used exclusively on the entire orchard or on specified clones. Genetic gains resulting from this procedure could be appreciable in many cases.

It is clear that more research is needed before supplemental pollination could become a routine operational reality. Nevertheless, some orchardists have already made trial applications. I will predict that in the near future many more orchardists will be seriously considering this technique.

LITERATURE CITED

Denison, N. P. 1971. The development and a review of tree breeding in the Republic of South Africa. Working Group on Breeding Tropical and Subtropical Species. Section 22, 15th IUFRO Congress. Gainesville, Fla., U.S.A.

Franklin, E. C. 1970. Survey of mutant forms and inbreeding depression in species of the family Pinaceae. Southeast. Forest Exp. Sta., USDA Forest Serv. Res. Pap. SE-61, 21 pp.

Franklin, E. C. (In press). Estimates of frequency of natural selfing and of inbreeding coefficients in loblolly pine. Silvae Genetica.

Sijde, van der, H. A. 1970. Bending of trees as a standard practice in pine seed orchard management in South Africa. Proc. Second World Consultation on Forest Tree Breeding, Vol. 2, FO-FTB-69-11/9: 1373-1379.

Squillace, A. E. 1967. Effectiveness of 400-foot isolation around a slash pine seed orchard. J. Forest. 65(11):823-824.

NANTUCKET PINE TIP MOTH CAUSED FLOWER AND CONELET MORTALITY

Harry O. Yates, III [1]

The seed orchard program in the South is of particular interest to me historically. My first assignment as an entomologist with the U. S. Forest Service in 1958 was to work with the Georgia Forestry Commissions' Arrowhead and Horseshoe Bend seed orchards at Cochran and Glenwood, Georgia. At that time these orchards were in their infancy and work was concentrated with establishing stock trees and grafting of superior scions. Today these orchards, and many others throughout the South, are producing annual crops of seed.

Certainly few insect pests have generated such universal concern in seed orchards as tip moths. In the past this concern in some cases was difficult to justify. There is no doubt that tip moth damage can appear to be devastating when every shoot on a young seed orchard tree is dead and brown, however there is still some question as to the real impact that tip moths have on seed production.

The first published concern about the impact of tip moths on seed orchard trees appeared in a paper by Zak in 1956. His immediate concern was with the effect tip moths have on initial survival of outplanted grafted stock. While tip moths can seriously injure young trees, it is doubtful that any tree mortality can be directly related to this insect.

Zak further contended that tip moth damage on productive trees may destroy terminal buds containing embryonic flower buds and thus reduce seed yields. This is a valid concern. If tip moths attack and kill the shoots and associated overwintering buds, then the primordia are lost and no conelets are produced the following spring.

In 1966 we conducted a study on loblolly pine, *Pinus taeda* L., at the Arrowhead Seed Orchard and on shortleaf pine, *P. echinata* Mill., at a seed orchard at Athens. The shoots of these producing seed orchard trees were artifically pruned to simulate tip moth attack. These artificial attacks were repeated throughout the spring and summer to generally coincide with the three or four tip moth generations. The terminal one-inch of all shoots on selected branches was pruned with shears and each branch tagged. An adjacent branch of the same size was similarly tagged but the shoots were not pruned. During the spring of the following year (1967) counts were made of the number of flowers developing on the unpruned branches (checks) and the adjacent pruned branches (treatments). A ratio was obtained by dividing the number of flowers developing on the pruned branches into the number of flowers developing on the unpruned branches. The higher this ratio the greater the effect the treatment had on flower production. These data show that the influence simulated tip moth damage has on flower production increases as the season progresses (Figure 1).

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[1] The author is research entomologist at the Forestry Sciences Laboratory, which is maintained at Athens, Georgia, by the Southeastern Forest Experiment Station, Forest Service, U. S. Department of Agriculture.

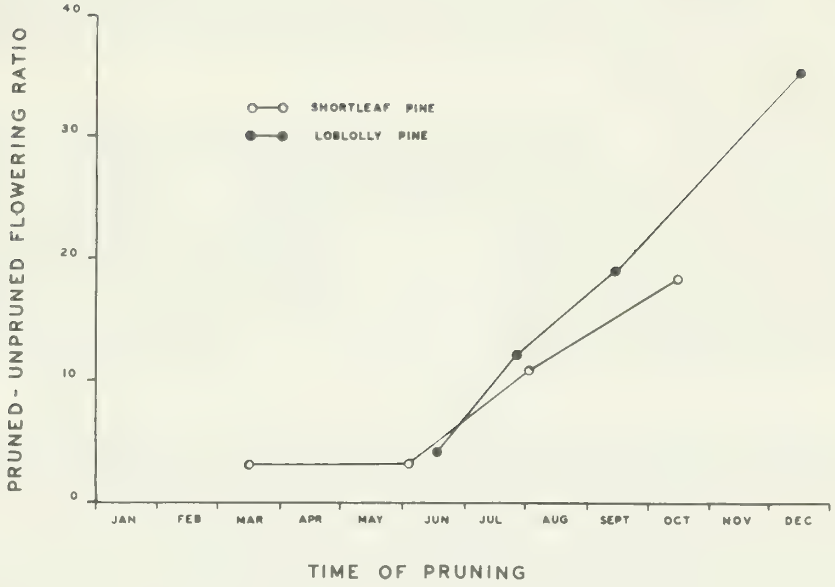

Figure 1.--Unpruned-pruned flowering ratio shows the increasing effect artificial tip moth damage (pruning) has on flower production as the growing season progresses.

More recently we have found in studies with both loblolly and shortleaf pines that this simulated tip moth injury is not necessarily a true measure of the actual effect tip moth can have on flower production. We have observed fall tip moth damage to shoots in the tops of trees which are similar in size and fruiting ability to producing seed orchard trees. Based on our clipping study this would be the most hazardous time to have tip moth attack. However, this late season attack generally is comparatively mild. In most cases only the terminal bud is hollowed out leaving lateral dormant buds uninjured. The uninjured lateral buds on these tip moth attacked shoots will successfully flower the following spring if they contain flower primordia.

Thus, tip moth shoot attack in the fall of the year does not always limit flower production the following spring. It depends largely on whether or not all the overwintering buds on the attacked shoot are killed.

In 1968 we started a 2-year study to determine the impact of various mortality factors on shortleaf pine seed production in the Georgia Piedmont. Five open grown shortleaf pines (25-30 ft.tall), similar in shape and cone production to trees growing in a seed orchard, were selected for study. Branches were selected and examined at 2-4 week intervals during the growing season. Each first-year conelet was examined, its condition noted, and causes of injury or death recorded. This provided observations for two years of first-year conelet mortality factors.

During our bi-weekly examinations of the sample branches in 1968, we observed minute boring frass on conelet surfaces. At first we attributed this conelet injury to *Dioryctria amatella* (Hulst) -- an important cone destroying insect of all southern pines. During subsequent sampling periods, it became apparent that *D. amatella* was not causing this damage. In May we reared an adult from these conelets which was identified as *Rhyacionia frustrana* (Comst.), the Nantucket pine tip moth. By July 15 it was apparent that tip moth was a major cause of conelet mortality on shortleaf pine.

First indications of tip moth injury consist of minute frass on the conelet surface resulting from first instar larval boring. As larval feeding progresses, a small quantity of oleoresin may accumulate around or over the lesion.

The second instar larvae migrate from the conelet to the supporting shoot. This migration is evidenced by a loose network of webbing which is laid down on the tip of the shoot and the adjacent injured conelet. A tent of webbing is constructed generally in the angle formed by the shoot and the conelet stalk. Once this tent is completed feeding within the conelet renews. Most commonly boring begins in the conelet stalk and extends up into the conelet thereby causing its death. The tip moth larva then migrates either to the shoot tip or to a healthy conelet to continue feeding and development. This results in the death of additional conelets or the tip of the shoot. Pupation occurs in these dead structures. The webbing and oleoresin-covered tent keep the dead conelet from dropping off the shoot immediately thus permitting damage evaluation for a longer period of time.

Larval feeding during the first tip moth generation commenced during the 3rd week of April in both 1968 and 1969. A majority (98.3%) of all tip moth-caused conelet mortality occurred during the first tip moth generation. However, in September 1968 and 1969, during the third generation, slight tip moth-caused conelet mortality was observed.

The impact of tip moths on conelet mortality is graphically illustrated in Figure 2. The two inserts at the bottom of this graph show the incidence of conelet mortality caused by tip moths. These inserts agree in time with the horizontal axis of the graph and the vertical axes are drawn to the same scale as the vertical axis of the parent graph.

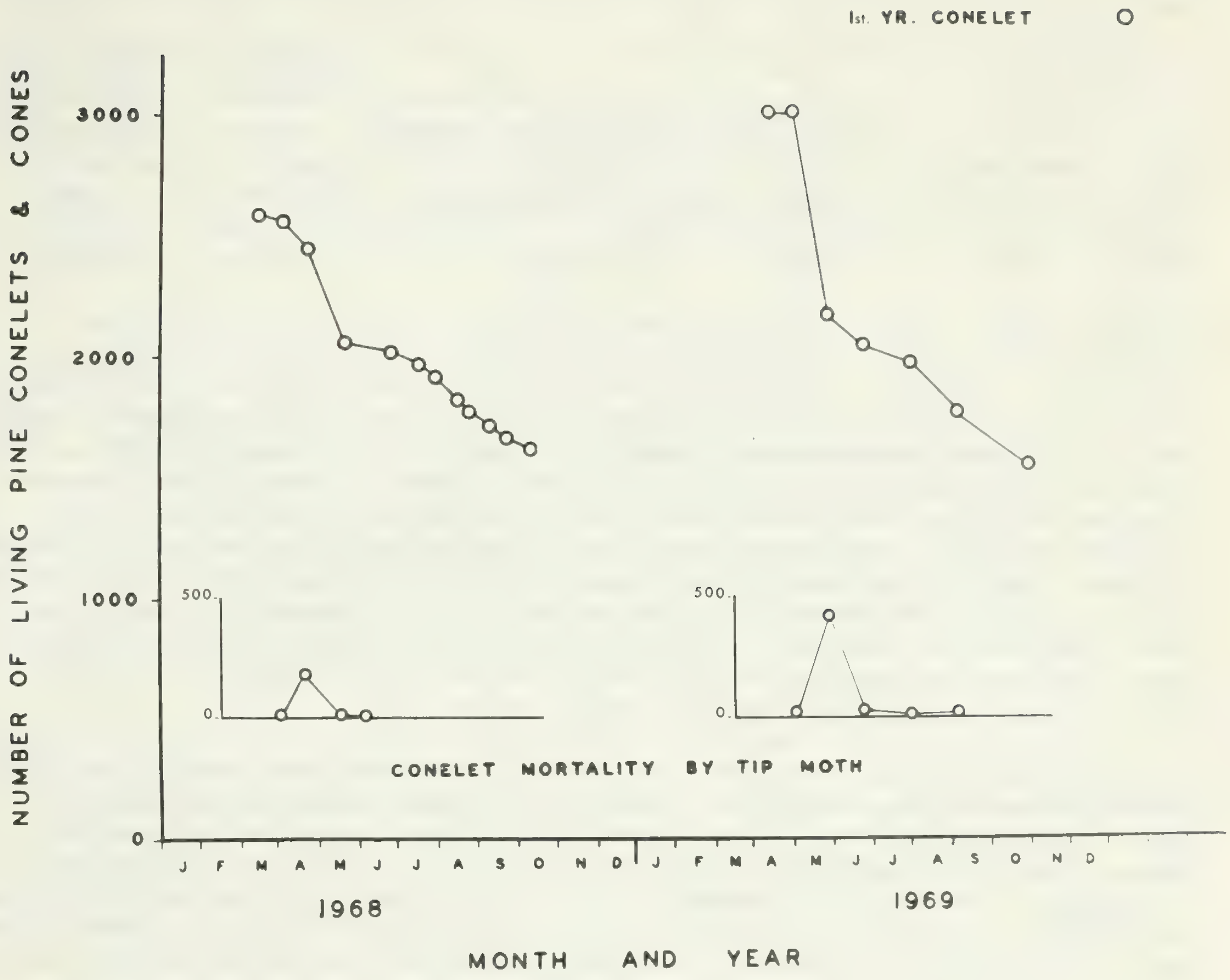

Figure 2.--Survival of first-year conelets during two seasons. Inserts indicate time and incidence of tip moth-caused first-year conelet mortality.

During both years of the study the most dramatic mortality to first-year conelets occurred in the spring. From April 21 to June 26, 1968, 569 of the first-year conelets died. Of these dead conelets 212 (37.3%) were killed by tip moth larvae. Similarly during this same period in 1969, 981 conelets died of which 445 (45.4%) were attributed to tip moth infestation. Expressed on the basis of total first-year conelet loss during each of the two study years these losses were 21.9% in 1968 and 31.3% in 1969 (Table 1).

During October of 1969 the second-year cone crop was harvested (a product of the spring 1968 conelet crop). At that time only 1208 sound cones were collected from the original 2591 conelets. This represented only a 46.6% harvest. Of this two year loss, 15.3% could be attributed to tip moth feeding on conelets, and was the largest single insect-caused mortality factor observed on shortleaf pine cones (Table 1).

Table 1.--Shortleaf pine conelet losses due to tip moth during 1968 and 1969

Year	1st year conelets April 3	Conelet loss during first season		Total conelet/ cone loss to harvest	Percentage tip moth-caused loss of harvested crop
		Total	Tip moth-caused mortality		
1968	2591	970	212 (21.9%)	1383	15.3 [2]
1969	3031	1482	464 (31.3%)	--	--

A study similar to this shortleaf pine study was conducted during 1969 and 1970 in open grown loblolly pine in Oconee County. The shortleaf and loblolly pine study areas were both in the Piedmont of Georgia and separated by about 15 miles. Only minor tip moth-caused mortality to loblolly pine conelets could be found (less than 1%). Observations of shortleaf pine adjacent to these loblolly pine trees established that tip moth was active in this area and was causing considerable conelet mortality. No comparative counts were made between these two pine species but incidental observations indicated that tip moths were as abundant on these adjacent shortleaf pines as they were on the shortleaf pine study trees in Clarke County.

On shortleaf pine the Nantucket pine tip moth was the greatest single identifiable factor causing mortality of first-year conelets. During two years of observation, two other conelet mortality categories exceeded or approximated the importance of tip moth. These included conelets aborted or missing. The abortion category (25.6% in 1968 and 28.9% in 1969) represents all conelets that died without damage symptoms. This death was assumed to be due to physiological factors. The missing category (36.7% in 1968 and 28.2% in 1969) accounted for the most conelet loss during the two years. These conelets were missing on subsequent sample branch observations, and thus no cause for conelet disappearance could be established. However, this does not preclude their death by tip moths.

The fact that nearly all of tip moth-caused mortality occurred during the two month period April to June 26 should provide a fairly good opportunity for the application of effective controls. Control using either contact or systemic insecticides directed to be effective during the second or third week of April should significantly reduce tip moth-caused conelet mortality. Since conelet mortality by tip moths did not occur during the second tip moth generation, only one insecticide application per season would be necessary.

Let's review the past and present tip moth controls that have been used and are now open to the seed orchard manager. Periodic sprays of organochlorine compounds, which were so successfully employed in the past, are no longer registered for tip moth control. The much used and very successful systemic insecticide phorate (Thimet®) enjoyed a brief history of registration until April of this year when the American Cyanamid Company withdrew all registrations of Thimet for forest use. The reasons for this action were "Thimet's extreme toxicity and the lack of safe methods with which to apply it." This leaves us with only one registered pesticide for control of tip moths in seed orchards. This compound is dimethoate or Cygon®. The recommended control is to drench the terminals with a 0.12 percent water emulsion of dimethoate. While this material is systemic it may be necessary to repeat sprays each generation to obtain control for the complete season.

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[2] Crop harvested in 1969.

In the past tip moths were generally regarded as insects that indirectly affect flower production in seed orchards. However in view of our recent studies we find they cause conelet mortality by direct feeding. Tip moths should therefore be viewed with greater respect as a potential seed orchard pest. This is particularly true of shortleaf pine seed orchards.

In certain instances the importance of tip moths during the summer and fall can now be minimized. Their major impact occurs in the spring of the year when direct conelet feeding can cause significant mortality.

LITERATURE CITED

Yates III, H. O., and B. H. Ebel. 1971. Shortleaf pine conelet loss due to the Nantucket pine tip moth *Rhyacionia frustrana* (Comstock) (Lepidoptera: Olethreutidae). Submitted for publication in the Ann. Entomol. Soc. Amer.

Zak, B. 1956. Seed orchards. Forest Farmer 15(12): 8,9,16,17.

LONGLEAF GRAFTING TECHNIQUES

Winton L. Slade [1]

The Stuart Orchard located on the Kisatchie National Forest near Alexandria, Louisiana has investigated three methods of grafting longleaf pine (Pinus palustris). The methods we have used are soft tissue grafts, grafts on potted understock, and grafts on understock planted in place in the orchard. Results obtained from grafting soft tissue and potted understock were not satisfactory for our purposes. Both of these methods gave only limited grafting success and poor early growth. The modified cleft graft used on understock planted in place is the method that will be described in this paper.

Production of understock suitable for grafting is our first consideration. One year old seedlings are planted in the orchard. These plants are hand weeded and sprayed for control of brown spot during the two to three years that are required for height growth to begin. When the shoots are from eight to twenty inches in length, the understock is ready to graft.

We collect scions between January 15 and February 15. Vigorous terminal buds are collected from the upper one-half of the crown. They should be at least six inches long. After being cut the scions are placed in polyethylene bags containing wet sphagnum moss. The bags, containing ten scions each, are placed in ice chests for transporting to the orchard. Polyethylene bottles of frozen water are placed in the bottom of the chests to keep the scions cool while in transit. The bags of scions are tagged inside and outside to prevent loss of identity. After arriving at the orchard, the scions are prepared for grafting and then stored at 36 degrees F. Preparation includes inspection to insure there is no insect damage, removing all needles, and dipping in a latex and water solution. We feel that this mixture of one part latex and eight parts water reduces loss of moisture while the scions are in storage.

At the Stuart Orchard, we like to graft between February 15 and March 15. These dates will vary from orchard to orchard. Materials needed for grafting are: sharp grafting knife, whetstone, pruning shears, rubber grafting strips, plastic grafting tape, and aluminum foil strips. Scions of only one clone are placed in an ice chest and given to an individual grafter for grafting. This permits close supervision and insures the identity of ramets. When the grafter reaches the desired understock, he selects a scion and then cuts about one inch from the end of the stem in order to expose fresh tissue. Understock terminal bud has needles removed from six to eight inches and then the cleft cut is made. Tapering cuts about five inches long are then made on opposite sides of the scion to produce a wedgeshaped section for insertion into the understock. As the scion is placed into the cleft, cambium layers of the scion and understock are carefully aligned on a single side. Alignment on just one side is usually necessary because frequently the understock bud is much larger than the scion.

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[1] The author is Project Forester on the Stuart Seed Orchard, Kisatchie National Forest.

While the scion is held firmly in place, the graft is securely wrapped with rubber grafting strips. The plastic grafting tape is then applied to give the graft some protection and to prevent rain from flowing freely into the cleft. The aluminum foil strips are wrapped around the graft and bud. This reflects sunlight and prevents the scion from drying out before union with the understock has occurred.

We have found that post-grafting care is an important factor. This care includes: regular inspection of the foil wrapper, especially after periods of strong wind or heavy rain; periodic removal of the foil and plastic grafting tape to break off adventitious buds that form on the understock; and cutting the grafting tape off after union takes place. Our grafting of longleaf for 1970 was as follows:

Geographic Source	Grafts Attempted	Grafts Surviving	% Take
Texas	308	225	73.0
Louisiana	2135	1071	50.1

The better grafting take for the Texas source was attributed to the better quality scions received.

HARDWOOD GENETICS AND ORCHARD DEVELOPMENT

Head Tablers

HORTICULTURAL TECHNIQUES IN HARDWOOD SEED ORCHARD MANAGEMENT

Thomas G. Zarger [1]

Possibilities of improving hardwoods through genetics are documented in some of the first Southern Forest Tree Improvement Committee reports, but Committee sponsored activities and action programs of the "fifties" centered on pine rather than hardwoods. The chief reason was a practical one. Pines represented the major planting effort, and it is within the broad area of reforestation that general principles of improvement can best be applied.

Pine tree improvers became busy testing geographic seed sources, selecting superior trees, and establishing seed orchards. We developed a new vocabulary--words strange to most foresters and forest managers of that day, but well known in the field of horticulture. We were thankful for Snyder's (1959) "Glossary for Tree Improvement Workers," which made it possible for us to converse on equal terms.

Little was known about pine seed orchard management but in a very short time successful techniques were developed and much of the establishment work became routine. For the most part, newly planted ramets survived, grew well, flowered, and were soon producing cones and seed. This is not to say everything was easy. There were stock-scion incompatabilities, failure of individual clones to flower, insect and disease problems, and now harvesting difficulties as enumerated by Kellison (1971). But, progress has been rapid and generally rewarding.

This synopsis of early activities is to remind you that hardwoods were given little attention in the "fifties" and to suggest that we turned to horticultural techniques more than realized for help with pine. Trials with some of the techniques did prove ineffectual, but one must remember horticultural practices were developed primarily for use on deciduous hardwoods and not conifers. It is in the field of hardwood seed orchard management--whether clonal or seedling--that horticultural techniques will become important.

"Techniques of seed orchard management with forest trees are more closely allied to fruit orchard problems than they are to conventional forestry problems." Foster (1967) concluded this after attending a symposium of the American Society for Horticultural Science held in conjunction with meetings of the American Institute of Biological Science at College Station, Texas, in 1967. Ten years before, Sax (1957), in studies on growth and fruiting of apples, suggested that methods used by horticulturists may have application to timber trees as well as fruit and ornamentals, and even earlier, various tree improvement workers proposed turning to the field of horticulture for solutions to pressing seed orchard problems. Foster was referring to TVA seed orchard goals which are to obtain quantity production of improved seed of black walnut, black cherry, chestnut oak, northern red oak, white oak, and yellow-poplar, and to get orchard trees in best form for rapid, efficient harvest of seed crops.

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[1] Staff Forester, Tree Improvement and Nutrition Section, Division of Forestry, Fisheries, and Wildlife Development, Tennessee Valley Authority, Norris, Tennessee.

The question that first comes to mind is how can production practices of the fruit tree orchardist have application in hardwood seed orchard management. The horticulturist works with different tree species and is interested in a different end-product. His chief concern is with the outer perishable, fleshy part of the fruit that encircles the seed. He seeks to produce fruits of optimum color, firmness, texture, flavor, size, and keeping quality.

Even harvesting and storage techniques are designed to protect the fleshy or pulpy tissues. With the above objectives it is apparent that the fruit tree orchardist has more complex production problems. But one may also assume that the cultural practices that result in a quality fruit are probably those that produce a sound seed with viable embryos.

The forest tree seed orchardist, like the horticulturist, is interested in cultural practices that promote annual bearing, maximize yields and facilitate harvest. In addition, he wants the seed to be large, uniform in size, and to maintain good germination potential through an extended storage life.

HORTICULTURAL CONTROLS

Among controls used by orchardists to increase production of fruit and nut crops are tree spacing, cultivation, irrigation, mineral nutrition, mulching, pesticides, herbicides, growth regulators, rootstocks, pruning, and tree training. When applicable, controls are regulated to facilitate mechanical harvest.

Spacing. Tree spacing is tailored to provide for efficient operation of machinery in cultural and harvesting operations and also give maximum yields of quality fruit per acre. Depending on whether fruit trees are on dwarf or regular rootstock, spacing may vary from as close as 10 x 14 feet to a maximum of 30 x 30 feet. The trend is toward more trees and closer planting. Wright (1968) reports one Pennsylvania orchardist has 50 acres of semi-dwarf apples on trellises at close spacings of 10 x 14 and 12 x 12 feet. Another 350 acres on standard rootstock at wide spacing is being converted by interplanting with semi-dwarf varieties. Hedgerow or fruiting wall planting used extensively in Europe presents a straight, unbroken fruiting surface, and lends itself to economic machine harvest (Anon. 1968). More trees can be planted per acre, and cross alleys, usually a maintenance problem, are eliminated. The trend to high-density planting and maximum production per acre is also of interest to peach growers who are conducting trials of training systems, including tree walls, for growing trees at high density--up to 220 trees per acre (Owen 1968).

Georgia pecan growers who seek high yields per acre plant trees at 40 x 40 feet and thin on diagonals when crowding occurs (Livingston and Fletcher, 1967). Twenty years ago walnut growers on the West Coast planted orchards at 50 x 50 feet, but now are planting at 30 x 30 feet. Martin et al (1969) found yields per tree similar at these and intermediate spacings early in the life of an orchard but unit area yields later increased proportionately to the number of trees per acre. Today, West Coast researchers are suggesting trials at 27 x 27 and 20 x 20 feet.

Cultural Practices. Horticulturists make wise use of cultivation, irrigation, and other cultural practices to improve growth of newly planted orchards, and to increase fruit and nut yields. For guidelines, orchardists rely on the work of researchers at state and federal experiment stations. Only a few of the many available references need be cited to illustrate the different kinds of research. An example is the work of Simmons (1965) on the relationship of soil cover practices and their variable effects on conservation and availability of soil moisture. Another is the study by Merrill (1952) on the beneficial effects of irrigation, hoeing, mulching, and herbicides on the growth of newly planted tung trees. With respect to fruit size and yield of peaches, Feldstein and Childers (1957) reported supplemental irrigation can be a benefit during periods of soil moisture shortage. For young pecan trees, Livingston and Fletcher (1967) recommend the soil area around the trees be kept clean of weeds and grass; for trees in production they recommend clean culture management in combination with planting winter cover crops.

Stephens and Jaynes (1969) report that cultivation, mulching, or incorporating organic matter into the soil when transplanting trees helps maintain conditions favorable for growth of nut tree species. These cultural practices improve soil aeration, thus increasing ability of tree roots to function efficiently.

Fertilization. Growers of horticultural crops are well versed in the nutritional requirements of major fruit and nut species and can recognize mineral soil deficiencies by amount of growth, abnormal leaf color, and other leaf characteristics. Horticulturists were among the first to chemically analyze plant tissues for determining concentration of elements and mode of nutrition in plants (Thomas, 1937; Frear and Anthony, 1943). The kind and amount of fertilizer needed depends on soil type and nutrient requirements of individual trees. In all, 14 elements--5 major and 9 minor--must be supplied by the soil for normal plant growth (Stephens and Jaynes, 1969).

Much reliance is placed on the value of nitrogen in promoting growth and yields. It has proven to be important with apple (Overholser et al, 1942), peach (Schneider and McClung, 1957), almond (Proebsting, 1937), pecan (Livingston and Fletcher, 1967) and black and Persian walnut (Stephens and Jaynes, 1969). The rate of application of nitrogen and other key elements depends on the amounts available in the soil and the amounts removed by the tree through growth and fruiting processes.

Tree Manipulation. Fruit tree orchardists control growth and fruiting mechanically, by planting cultivars grown on dwarfing understocks and with chemicals. Mechanical practices include top and root pruning, girdling and/or inverting the bark on the trunk of the tree, ringing, stem-knotting and training branches to grow on wires or trellis in a horizontal position. Sax (1957) reports knotting of the rootstock stem or interstock promotes earlier flowering and that inverting a ring of bark before or during the normal time of flower bud initiation induces fruiting the following year. This manipulation temporarily slows vegetative growth but needs to be repeated. Dwarfing rootstock exerts a permanent influence and keeps tree size small for more efficient cultural and harvesting operations.

Chemicals are used to shape trees and regulate flowering and fruiting. One of the more promising, Alar (N, N dimethylamino succinamic acid), has been called the wonder chemical in horticulture. On apples it reduces shoot growth, promotes flower bud formation for the next season, prevents preharvest drop of fruit, and may delay flowering in the spring for frost protection (Wittwer, 1969).

Advances made with chemicals in controlling fruit drop are part of the reason for the swing to mechanical harvesters. As a result of this and a shortage of labor, manufacturers across the country are offering machines for harvesting deciduous tree fruits, grapes, berries, and nuts. They range from one-man lifts for hand-picking to self-propelled harvesters which can gather up to two tons of blueberries per hour. In between there are tree shakers and catching frames for soft fruit harvesting. Some tree shaking machines come equipped with pick-up reels or are used with a vacuum unit for gathering nuts. So the orchardist gears his management operations to fit advances made in harvesting machinery.

APPLICATION IN SEED ORCHARD MANAGEMENT

Total acreage in the U. S. now in hardwood seed orchards probably does not exceed 100 acres but may involve 10 or more species. Most of this acreage is in clone banks in trees not yet of production age. Before horticultural practices as described above can be adapted for seed orchard use, more information will be needed on growth habit and on flowering and seeding characteristics of each species. By utilizing current knowledge and by applying cultural techniques in seed orchard trials, we can begin evaluating treatment effect on seed production and on tree growth and vigor. We need to work closely with tree physiologists who also turn to horticultural literature for help with their problems. In the TVA tree improvement program three scientists devote full time to the physiology of hardwoods. Our field trials usually start where they leave off. My remarks on technique application will refer primarily to black cherry, black walnut, yellow-poplar, and three oaks--chestnut, white, and northern red.

With regard to spacing controls, we can be satisfied with one standard planting distance or follow the lead of horticulturists and determine the most effective orchard spacing for each species. Since good orchard sites within convenient travel distance are at a premium, we should aim for maximum production per unit area. Spacing trials should emphasize high density plantings, at least when the trees are small. Proponents of hedgerow plantings claim tall, narrow walls of hedgerows produce as much bearing surface as a series of hemispheres. We should also consider group or clump plantings of different clones. Both group and hedgerow plantings could aid cross-pollination of species like yellow-poplar and black cherry. Until dwarfing understocks become available, tree planting densities in hardwood orchards will not approach that found in fruit orchards.

Taft (1966) determined that a tree spacing of 20 x 20 feet would be adequate to age 12 and 40 x 40 feet to age 32 for new TVA black walnut seed orchards. His calculations were based on crown measurements available on 32-year-old walnuts growing at a 50-foot spacing in a TVA nut orchard. Planting at the 20-foot spacing increased tree density from 17 to 109 trees per acre.

No one questions that soil cultural practices will pay off in the early life of the orchard, and later, as trees come into bearing. However, we will find one method of management is needed for young trees and another for trees of production age. We know newly planted trees will respond to treatments that keep down weed growth and conserve soil moisture. One factor in determining what method to use will be operational cost. Another is the total benefit which is manifest in tree growth and development. Annual mulching will cost more than herbicidal applications but yield more direct benefits by preventing soil movement and surface washing, reducing extremes of soil temperature, reducing soil moisture losses by direct evaporation, and improving the soil gradually during the course of decomposition of organic matter. Mechanical cultivation to control annual and perennial weeds and grasses may cause root damage to young trees and is costly because repeated treatments are needed to be effective. One disadvantage of mulching is possible damage to trees from rodents which burrow and hide under the mulch.

In orchards of production age a sod cover should be maintained until more is known about long-time effects from clean cultivation and repeated herbicide treatments. The orchardist should guard against development of too thick a sod which prevents proper soil aeration for optimum tree growth.

Fertilization goes along with soil cover management but very little is known about orchard requirements for the species under consideration here. Like pecan (Livingston and Fletcher, 1967) trees should be fertilized enough to maintain some minimum annual terminal twig growth to keep trees in production. This could require single applications of a complete fertilizer with additions of nitrogen as needed. Time and rate of applying fertilizer should be determined for the particular species and orchard site and related to amount of nutrients removed by growth and yield functions. In considering fertilization, foresters tend to overlook lime which could be significant with hardwoods. Leaf analysis for determining nutritional needs is a tool that will become more useful than soil testing once requirements of individual species are known. Eventually, leaf analysis services will be available through laboratories maintained by your state universities.

The major breakthrough with horticultural techniques will be in the area of tree manipulation. A first step is to learn how to train and prune young trees. By selecting shoots to form the future framework of the tree and deshooting undesirable ones, we later avoid large pruning cuts that are slow to heal and invite decay. All the growth goes directly to selected branches. Follow-up pruning will be light--for shaping and to encourage early bearing. Studies (Krajicek and Bey, 1969) by the U. S. Forest Service at Carbondale, Illinois, are already providing information on how to train black walnut seedlings. Findings will have application in black walnut seed orchard management.

Secondly, we must test various mechanical treatments to find out if they contribute to early flowering. There is evidence that yellow-poplar will respond. This spring Taft [2] observed heavy flowering on young, six to eight-foot ramets in the orchard at Norris, Tennessee--on trees that developed bark splits from low temperatures during the winter of 1969-70. Taft also noted the flowers occurred on secondary branches rather than on terminal leaders, which suggests that pruning or other mechanical treatments will favor development of this type growth.

We should determine the value of dwarfing understocks for growth inhibiting effects and their ability to influence early flowering. Their use may prove unimportant with heavy seeded species such as the oaks and walnut whose seed falls to the ground.

We need to investigate the role of chemicals, especially retardants like Alar, in regulating growth and flowering of seed orchard species. Based on horticultural experience they could help us by (1) keeping trees small by limiting shoot growth, shortening internodes and thickening stems; (2) promoting flower formation in nonflowering clones; (3) delaying flowering in the spring to avoid late frosts; (4) facilitating time of flowering in dichogomous species like walnut; and (5) controlling abscission of fruits for more efficient harvest, as needed in black cherry. The retardants may also prolong storage life of oak and black walnut seed. While chemical retardants are highly specific and have proved ineffective with some plants, our species may be sensitive and respond. If so, they will have great seed orchard management potential.

To fully evaluate horticultural practices that may be effective in hardwood seed orchard management, it is desirable that orchards be established especially for test use. This eliminates factors that contribute to experimental error such as ramet age differences, unequal clone numbers and previous soil management and tree tendance practices. Trials should be initiated when the orchards are established and continue through the development stage to at least early maturity. Insofar as possible planting schemes should be designed to facilitate mechanical harvest. Obviously, all techniques in need of testing cannot be studied at one time or in a single orchard.

SUMMARY

As improvement efforts focus on hardwoods, seed orchard managers will find that orchard trees do not respond like pine but will require more intensive treatments if full development potential is to be realized. He will be interested in techniques that promote annual bearing, maximize yields, and facilitate mechanical harvest. The techniques will be those commonly used in horticulture today but which need to be evaluated for their application in hardwood seed orchard management. Among the

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[2] Personal communication with Kingsley A. Taft, Jr., TVA.

techniques and practices most likely to affect seed production and harvest are those related to tree spacing, soil culture and fertilization, and tree manipulation, which can be effected either mechanically or with chemicals.

LITERATURE CITED

Anon. 1968. They ride while they pick tree walls of fruit. Amer. Fruit Grow. 88(6) 11, 30.

Feldstein, J. and Horman F. Childers. 1957. Effect of irrigation on fruit size and yield of peaches in Pennsylvania. Proc. Amer. Soc. Hort. Sci. 69:126-130.

Foster, A. A. 1967. Eighteenth annual AIBS meeting, College Station, Tex. TVA Interoffice Memo. Oct. 3.

Frear, Donald E. H. and R. D. Anthony. 1943. The influence of date of sampling on the value of leaf weights and chemical analysis in nutrition experiments with apple trees. Proc. Amer. Soc. Hort. Sci. 42:115-122.

Kellison, R. C.. 1971. Seed orchard management. Proc. Eleventh South. Conf. For. Tree Improv. Atlanta, Ga. June 15-16. (In press.)

Krajicek, John E. and Calvin F. Bey. 1969. How to "train" black walnut seedlings. USFS North Cent. For. Exp. Sta. Brochure distrib. by USFS St. and Priv. For. Upper Darby, Pa.

Livingston, R. L. and R. Shaw Fletcher. 1967. Pecans in Georgia. Univ. of Ga. Ext. Ser. Bul. 609. Rev. Oct. 1967.

Martin, George C., Harold I. Forde, and Eugene F. Serr. 1969. Yield performance of (Juglans regia) 'Payne' on seedlings of northern California black walnut (Juglans hindsii) rootstock at three planting distances. Hort Science. 4(2):130-131.

Merrill, Samuel, Jr. 1952. Effect of cultivation, irrigation, fertilization, and other cultural treatments on growth of newly planted tung trees. Proc. Amer. Soc. Hort. Sci. 59:69-81.

Overholser, E. L., F. L. Overley, J. C. Wilcox, and D. F. Allmendinger. 1942. Statistical analyses of the fertilizer data from the Von Osten apple orchard. Proc. Amer. Soc. Hort. Sci. 41:19-22.

Owen, Frank W. 1968. High density peach plantings . . . a dream or reality? Amer. Fruit Grow. 88(12):11-13, 30.

Proebsting, E. L. 1937. Fertilizing deciduous fruit trees in California. Calif. Agr. Exp. Sta. Bul. 610, 29 pp.

Sax, Karl. 1957. The control of vegetative growth and the induction of early fruiting of apple trees. Proc. Amer. Soc. Hort. Sci. 69:68-74.

Schneider, G. W. and A. C. McClung. 1957. Interrelationships of pruning, nitrogen rate and time of nitrogen application in Halehaven peach. Proc. Amer. Soc. Hort. Sci. 69:141-147.

Simmons, Roy K. 1955. Effects of different orchard management practices upon availability of soil moisture. Proc. Amer. Soc. Hort. Sci. 66:1-6.

Snyder, E. B. 1959. Glossary for forest tree improvement workers. Pub. for the Soc. Amer. For. by USFS South. For. Exp. Sta. 22 pp.

Stephens, George R. and R. A. Jaynes. 1969. Soil management. In Handbook of North Amer. Nut Trees, pp. 13-17. North. Nut Grow. Assoc.

Taft, Kingsley A., Jr. 1966. TVA's hardwood tree improvement program. Proc. Southeast Area For. Nurserymen's Conf. Columbia, S. C. Aug. 23-24. pp. 24-31.

Thomas, Walter. 1937. Foliar diagnosis: Principles and practice. Plant Phys. 12:571-599.

Wittwer, S. H. 1969. Chemical regulators in horticulture. Hort Science. 3(3):163-167.

Wright, J. Earl. 1968. Heisey orchards cut costs with concentrate spraying. Amer. Fruit Grow. 88(6):39.

ROOTING CUTTINGS FROM SELECT YELLOW-POPLAR TREES

Robert G. McAlpine and Paul P. Kormanik[1]

Select yellow-poplar trees are commonly propagated by grafting. This method is used in lieu of a dependable process for rooting cuttings from mature trees. Own-rooted propagules, however, offer several advantages over grafted stock. Among these are their suitability for clonal testing on a variety of planting sites, testing for degree of resistance to certain root diseases and the elimination of the problems of incompatibility between stock and scion.

A method for producing own-rooted clones of yellow-poplar has been presented (McAlpine 1962). This method pointed out the ease with which softwood cuttings could be rooted under mist when prepared from young, rapidly growing stump sprouts. The value of this method lay in the multiplication of numerous ramets of several clones to be used primarily as research tools.

The ability to store such cuttings under refrigeration for periods up to two weeks without diminished rootability was determined by Steinbeck and Porterfield (1967). This enabled a worker to collect cuttings from sources spaced miles apart and store and ship these to a central area where mist beds were available for rooting.

Using this knowledge we have been able to bring together at Athens a number of yellow-poplar clones from widely scattered parts of Georgia and adjacent states. However, an obvious disadvantage of using stump sprouts to propagate a select tree is that the tree must be cut and is lost for other uses.

Kormanik and Porterfield (1966) were able to root newly-formed epicormic branches almost as well as stump sprouts. Sprouting was stimulated by placing girdles part way around the circumference of the bole at intervals of 3 or 4 feet from stump height to the base of the crown. These partial girdles were oriented on opposite sides of the tree so that on a given log face, the girdles were 6 to 8 feet apart. This effectively removed inhibition of the suppressed buds without severely damaging the tree. During the summer of 1970 epicormics produced by this process were collected from girdled trees in the piedmont and mountains of Georgia and rooted and lined out in a clone orchard.

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[1] The authors are, respectively, Principal Silviculturist and Research Forester, Forestry Sciences Laboratory, Southeastern Forest Experiment Station, Forest Service, U. S. Department of Agriculture, Athens, Ga.

Although this method has been used successfully, it has disadvantages. All trees do not produce sprouts even though girdles are improperly made. Old trees produce fewer sprouts than young trees. And, trees are usually selected because, among other things, they show a tendency to have fewer epicormics than comparison trees. The task of girdling a tree is difficult and time-consuming. The larger and taller the tree the more difficult is the job. Girdles improperly made are almost sure to be bridged by callous. And, to obtain adequate sprout formation neighboring trees must be felled to expose the bole to sunlight. These factors and the fact that a tree girdled from top to bottom is not aesthetically pleasing, limit the usefulness of the girdling method.

We have known for some time that it was possible to severely prune back the top of a well-established, grafted tree and cause the scion to sprout. Cuttings made from sprouts produced by the scion can be rooted reasonably well (McAlpine 1965). Own-rooted propagules thus obtained and outplanted can be used as a source of additional cuttings, and the clone thus multiplied. This method presupposes that the selected tree can be grafted in sufficient numbers so that at least one individual can be sacrificed for propagation purposes.

Recently we have taken a new approach to obtain sprouts from trees and at the same time we hope to reduce the time and effort required and to increase the certainty of sprouting. This involves pruning the crown of mature trees. The degree of pruning is yet to be determined, but we have begun a study which includes shooting out or sawing out the top or uppermost branches, pruning or shearing one side of the crown leaving branch stubs 2 to 4 feet long, and in like manner, pruning off all branches from the base of the crown up to about 1/3 residual top. All except shooting require climbing into the crown. This method offers an advantage over the girdling method in that the removal of surrounding trees to allow additional sunlight to reach the treated parts is not required.

Preliminary work has shown that conditioning a tree for sprouting by either girdling or pruning should be done during the dormant season. Any visible indication of beginning of bud growth in early spring means that treatment will likely be ineffective or that sprouting will be delayed until too late in summer for rooting.

Trees in the current study were treated in late February. Two trees in each of three age classes were treated by each of the four methods described. An inspection in mid-May revealed that sprouting was well underway on almost all trees. Thus far 1600 cuttings have been collected and placed in mist beds. Information on success in propagation will be available next year; however, we are confident that select trees can be propagated by one or more of these pruning methods.

LITERATURE CITED

Kormanik, Paul P., and Edward J. Porterfield. 1966. Rooting yellow-poplar cuttings. Forest Farmer 26(2): 24, 41-42.

McAlpine, Robert G. 1964. A method for producing clones of yellow-poplar. J. Forestry 62(2): 115-116.

McAlpine, Robert G. 1965. Vegetative propagation methods for hardwoods. In Proc. of the Eighth Southern Conference on Forest Tree Improvement, June 16-17, 1965: 14-20.

Steinbeck, Klaus, and Edward J. Porterfield. 1967. Short-term storage of yellow-poplar softwood cuttings. Southeast. Forest Exp. Sta., U.S.D.A. Forest Serv. Res. Note SE-71, 4 pp.

THE RAPID EXPANSION OF 14 SELECTED COTTONWOOD CLONES

James L. McConnell [1]

In the late winter of 1969 a project to produce 600,000 Superior Cottonwood cuttings was started by the Southeastern Area, Division of State and Private Forestry at the Forest Service's Southern Hardwoods Laboratory at Stoneville, Mississippi. Plans are to distribute the cuttings in the fall of 1971 to cottonwood-growing State and industrial nurseries in the lower Mississippi River Valley. Each year, approximately 6000 acres are planted to cottonwood in the rich alluvial bottoms of the lower Mississippi River Valley. Planters are actively seeking cottonwood clones that have proven superiority in growth rate and other economically important traits.

Scientists at the Hardwood lab began work in 1961 to select genetically improved trees to serve as a base for future breeding experiments. Randall and Mohn discussed the Cottonwood Selection Program at the 10th Southern Conference on Forest Tree Improvement.

The following is a description of the procedure used to vegetatively expand the 14 selected clones.

The initial planting area was a four-acre site that was fairly level, with enough slope to permit satisfactory drainage. An adequate water supply was close at hand. The site was divided into management blocks, with blocks for each clone. Rows within the blocks were spaced 40" apart. Because this is the standard row width used at the Delta Branch Experiment Station at Stoneville, interchange of equipment between projects was easily accomplished. There were 10 rows to each block and each row was 100' long. Cuttings were planted 1' apart in the rows, permitting the planting of 1000 individual cuttings in each block. A 10' aisle was left on the ends and sides of each block.

Initial cuttings came from small clone banks, survival test sites that had served their purpose, stump sprouts and tops from thinnings of long term studies. Most of the material consisted of one-year-old wands several feet long. In this initial stage numbers of plants were important, so the wands were cut into 12-inch lengths instead of the standard 20-inch field planted cutting.

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[1] Hardwoods Regeneration Specialist, U. S. Forest Service, SE Area, State and Private Forestry, Cooperative Forest Management, Stoneville, Mississippi.

Hardwood cuttings from the wands were cut with a 10-inch electric bench saw with a fine-toothed blade.

All short hardwood cuttings, tips and branches too small to make normal cuttings were cut into 6-inch lengths. These cuttings were placed in peat pots in the greenhouse, watered daily, and field planted as they rooted and the danger of late spring frost passed.

A major part of the rapid expansion project centers around the concept of mist propagation of greenwood cuttings. The mist technique makes possible the rooting of soft, succulent, fast-growing plant material. Also, intermittent mist will keep relatively slow-rooting cuttings alive for a long period of time, giving them a chance to root before they die of desiccation.

Elaborate equipment and facilities were not needed. Mist benches were constructed in the open in a small well-drained area surrounded by an 8-foot constructed windbreak. The benches, which hold approximately 360 greenwood cuttings, are built of redwood and are 4-feet wide, 12 feet long, and 3 feet off the ground. This affords the most comfortable working height and reach for project workers. The bottom of the mist bench consists of 1" x 2" galvanized hog wire that allows excess water to move away freely. Four inches of washed gravel provided a comfortable surface on which to work, although it remained wet.

The irrigation apparatus consisted of three 3/8" riser pipes 4 feet apart with mist nozzles on each bench. Half-inch pipe placed under the gravel supply water to the riser pipes and nozzles.

Cutoff valves, solenoid valves, line strainers and timing clocks were at one central location away from the mist benches. Six mist benches were built for the project with sets of two attached to a solenoid, filter and clock. This allows use of any combination of one to six mist benches at a time.

Two timer clocks and one 24-hour day-night or on-off timer regulates the mist cycles. One timer clock has a 30-minute cycle with 15-second trippers, the other has a 5-minute cycle with 2-1/2-second trippers. The clocks are mounted on a plywood control panel in a small metal building. Lines from the solenoid valves can be plugged into either mist cycle timer and the mist cycle timers can be plugged into the 24-hour day-night timer. (See Figure 1).

The normal water source at the lab supplies a 1,000 gallon storage tank which furnishes water to a 300-gallon pressure tank. Pressure in the tank is regulated by the pressure switch on the pump. Most mist nozzles operate best between 20 to 60 psi., although we have found the more pressure the better. The tank has a float valve that can be turned on at night or weekends when the demand for water at the laboratory is low. The 1,000 gallons of water is about a 3-day supply.

Use of the mist system for young, succulent, green plant material is adequate as long as the cuttings do not desiccate. Cuttings root best in the hot summer months, but they die after 10 minutes without water. The most commonly used solenoids are normally closed; when the tripper on the clock strikes the switch, the power flows and the solenoid opens. With no power the solenoid closes. A normally open solenoid works just the opposite. As long as you have electric power the normally open solenoid remains closed. (See Figure 2). If the power goes off the normally open solenoid opens and allows the water to flow for as long as there is no power. Thus the cuttings will not dry out during an unexpected power failure. Static pressure in the pressure tank keeps the nozzles on for about 60 minutes when electric power is off. On a hot day this feature could save an entire crop of cuttings. This solenoid is easily built into the system by connecting it to the front and rear of the normal control valves.

Rooting media consists of equal parts of perlite and sand, mixed in a 4-1/2 cubic foot, electric, portable concrete mixer. Twenty, 3-inch peat pots containing the media put into a flat and each flat contains cuttings from one clone which is identified by a 6-inch wooden pot label. A marked aluminum tag is dropped in the bottom of the flat in case the pot label is lost.

The best schedule for collecting greenwood cuttings is early in the morning while the dew is still on the plants. The fast-growing terminals are cut from the plants in the nursery with pruning shears and placed in ice chests containing tap water for transport to the mist benches. At the mist area, all but the terminal leaves are trimmed with a sharp knife and cut back to a uniform 6-inch length. Immediately after trimming the cuttings are placed in the prewatered media in the peat pots. A pencil-sized hole punched in the rooting media down through the peat pot allows excess water to run freely through the pot. Also the tender cuttings can be inserted without damage. Cuttings are placed in the rooting media while the mist is intermittently on.

The length and frequency of mist is an empirical thing and depends upon the temperature and amount of sunlight. A normal mist cycle on a hot clear day would consist of 5 seconds of mist every 20 to 30 seconds. In the early morning and late afternoon hours the time between mist can be lengthened and shut down completely after sundown. If constructed properly, all of the timing cycles can be worked automatically and need only periodic adjustments.

Under normal summer weather conditions in the deep South, hot days and warm nights, the cuttings root in 7 to 14 days. When roots appear through at least half the peat pots in a flat, they are moved out of the mist chamber and into a shadehouse (50% shade) for hardening-off. The sprinkling system has a timing clock with a 30-minute cycle and 15-second trippers. Thus the first day in the hardening-off shed the cuttings receive 15 seconds of water every 10 or 15 minutes. The second day the mist is cut back to 15 seconds of water every 20 to 30 minutes, and the third day, to each 30 minutes. Usually after 3 or 4 days in the hardening-off shed the cuttings are ready to plant in the field. Immediately after planting in the nursery they are thoroughly watered.

Disease is usually not a problem with the use of mist since the water spray tends to inhibit the development of powdery mildews. However, a black stem rot was a problem in the spring of 1970. The micro-organisms associated with the symptoms were Alternaria and a bacterum (rot shaped-gram negative). Alternaria has been implicated with other stem diseases. Further research is being conducted at Stoneville to determine the cause and control of this disease.

Frequent and thorough cultivations are necessary. When the plants are small, weekly cultivations are needed.

When the plants are small, a tractor-mounted cultivator does a fine job. Later, as the cottonwood plants outgrow the tractor, a rototiller appears to be the most efficient method of weed control with a small amount of hand hoeing.

Irrigation of the nursery area is done with a 6" 30-foot section portable aluminum irrigation pipe. Sprinkler nozzles on 8-foot risers are satisfactory initially but late in the season, as the plants grow, the risers need extending to 10 feet.

The first year we applied about 1" of water a week to the established plants. In retrospect, this is too much water. The stump diameter of many of the plants at harvest time was so large they had to be discarded.

However, newly rooted plants fresh from the mist area must be kept moist for at least two weeks after being planted in the field.

Insect control in the nursery was achieved with the systemic insecticide. The insecticide, carbofuran was used on an experimental basis with rates varying from 2 to 6 pounds per acre to control insects. More work is being done with this chemical at Stoneville. It shows great promise for the control of the cottonwood clearwing stem borer (Paranthrene dollii), the cottonwood twig borer (Gypsonoma haimbachiana) and the cottonwood leaf beetle (Chrysomela scripta). Carbofuran is a granular substance and was applied in the nursery with a subsoil blade about 6 inches deep.

During the winter of 1971 the dormant hardwood cuttings from the initial 4 acre cottonwood nursery were harvested, cut into 12" lengths and planted on an additional 12 acres. Cuttings from both of these nursery sites will be harvested in the winter of 1971-72 for distribution.

BIBLIOGRAPHY

Farmer, R. E., Jr. 1963. Distilled-water mist chamber for propagating greenwood cuttings. U. S. Dept. Agr. Forest Service Tree Planters' Notes 59, pp.28-29.

Hartmann, H. T. and Kester, D. E. 1968. Plant Propagation - Principles and Practices. Prentice-Hall, Inc., Englewood Cliffs, New Jersey. 702 pp.

McAlpine, R. G. 1966. Vegetative propagation methods for hardwoods. Eighth South. Conf. Forest Tree Impr. Proc. pp. 14-20. Ga. Forest Res. Council Pub. No. 24, Macon, Ga.

McKnight, J. S. 1970. Planting cottonwood cuttings for timber production in the South. USDA Forest Serv. Res. Pap. SO-60, 17 pp. Sou. For. Exp. Sta., New Orleans, La.

Mohn, C. A., Randall, W. K., and McKnight, J. S. 1970. Fourteen cottonwood clones selected for midsouth timber production. USDA Forest Service Res. Pap. SO-62, 17 pp. Sou. For. Exp. Sta., New Orleans, La.

Mohn, C. A. and Randall, W. K. 1969. Preliminary selection of eastern cottonwood clones. Tenth South. Conf. Forest Tree Impr. Proc. pp. 41-48. Sponsored Pub. No. 30 Sou. Forest Tree Impr. Comm., Eastern Tree Seed Lab., Macon, Ga.

Randall, W. K. and Miller, A. J. E. 1969. Rapid expansion of eastern cottonwood clones, In Press.

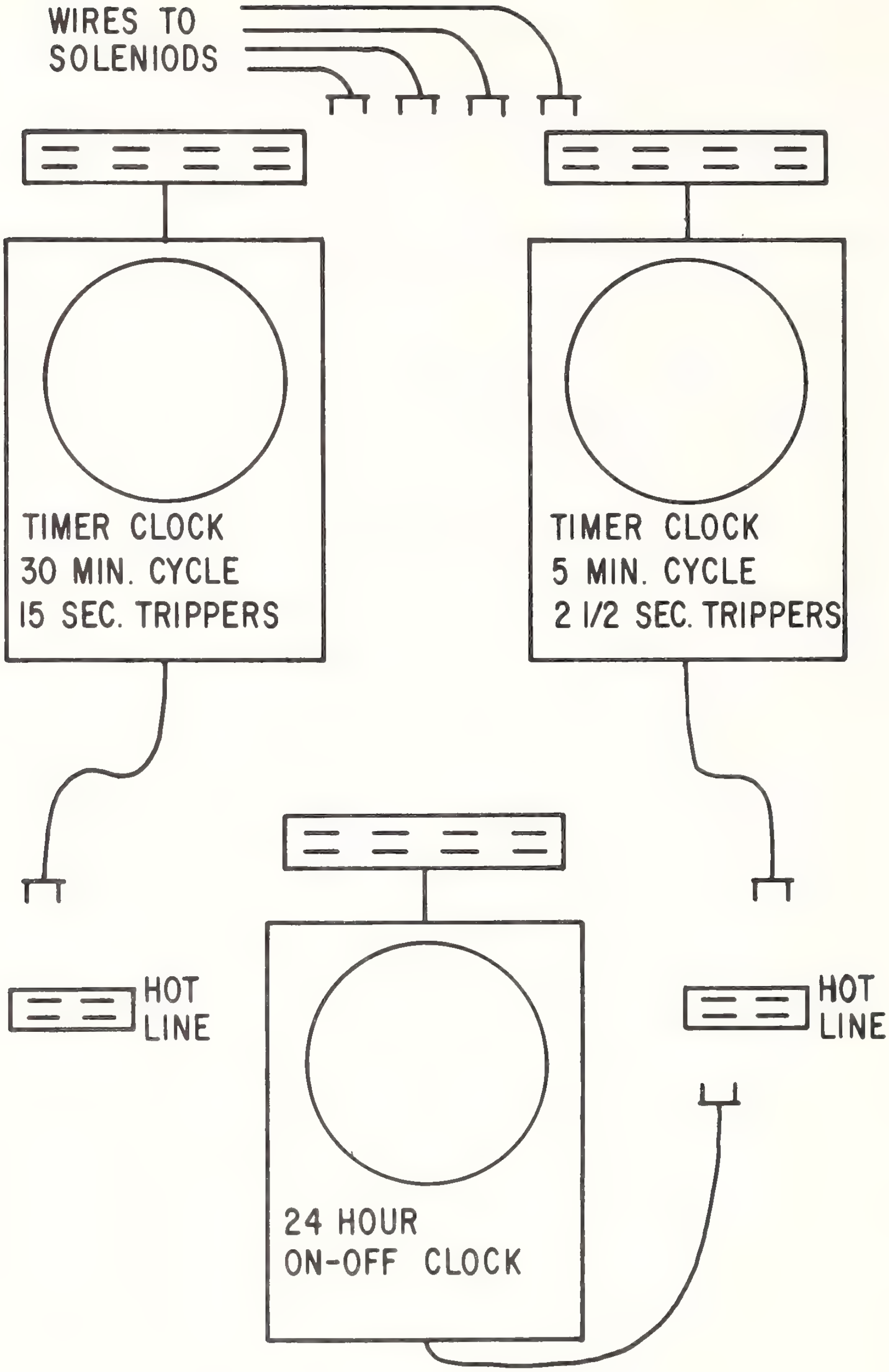

Figure 1. Diagram of clock central system

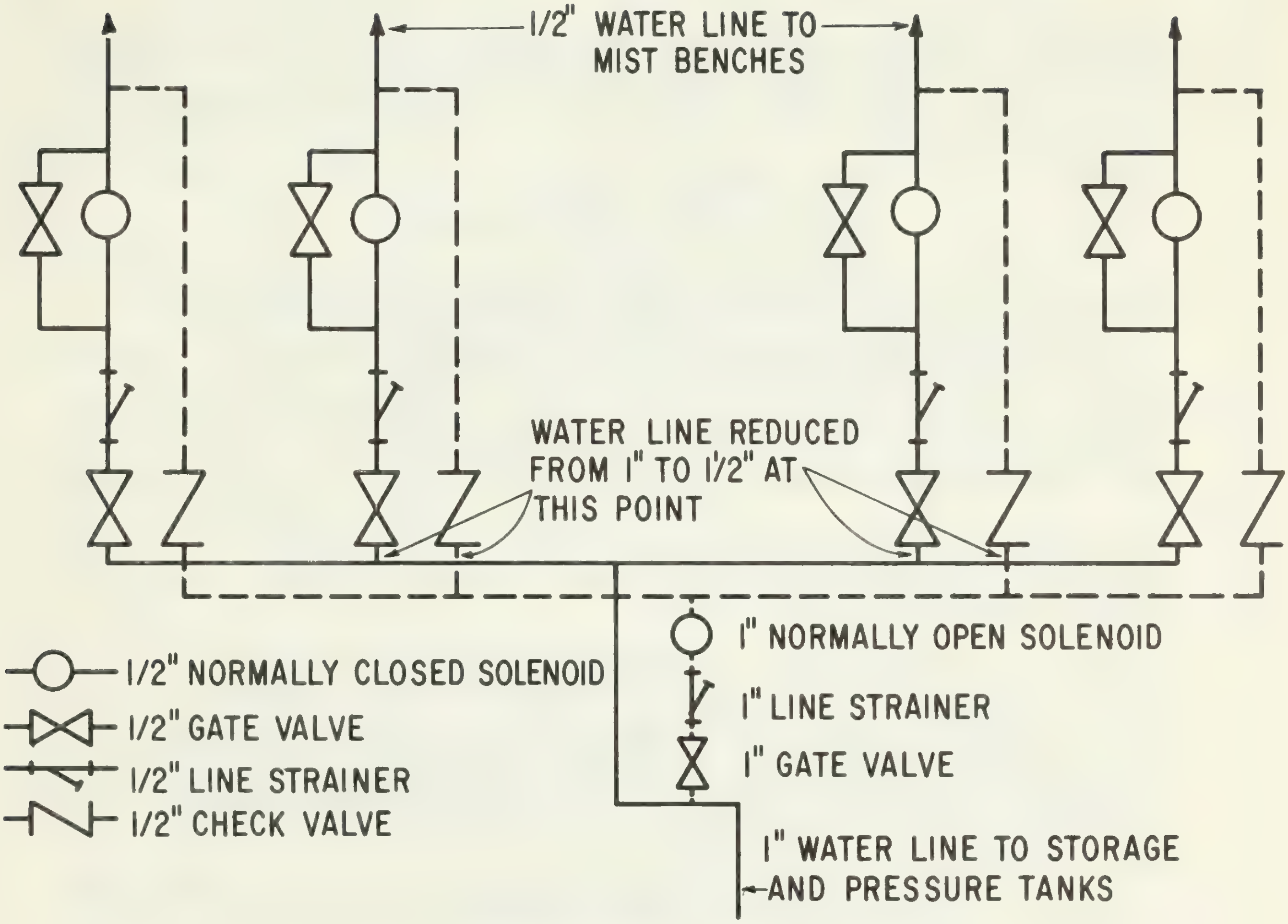
1/2" WATER LINE TO MIST BENCHES
WATER LINE REDUCED FROM 1" TO 1/2" AT THIS POINT
1" NORMALLY OPEN SOLENOID
1/2" NORMALLY CLOSED SOLENOID
1" LINE STRAINER
1/2" GATE VALVE
1" GATE VALVE
1/2" LINE STRAINER
1/2" CHECK VALVE
1" WATER LINE TO STORAGE AND PRESSURE TANKS

Figure 2. Diagram of water control system for mist propagation

HARDWOOD TREE IMPROVEMENT IN REGION 8

Walter E. Smith[1]

INTRODUCTION

Region 8 of the U. S. Forest Service, as most of you know, administers National Forest lands from Texas to the Atlantic Ocean and from Kentucky to the Gulf of Mexico. This area contains several hundred hardwood species, ranging from wetland to mountain types.

SOURCES OF HIGH QUALITY HARDWOODS

Analysis of timber management plans, special reports, and surveys showed that National Forests in the Region have about 239 thousand acres of bottomland hardwoods and 3.1 million acres of upland hardwoods growing on site index 60 or better. Site 60 was the selected cut-off point because this is about the lowest productivity class which will give an economic return to investment at the present time.

The bottomland hardwood types are on swamp lands or on lands subject to annual flooding. The upland hardwood types grow in both Piedmont and mountain areas.

In our pine selection work, we had to survey an area of at least 50 thousand acres to find the number of high quality trees needed for a Tree Improvement Program. On this experience and by using available data, we separated the Region into 11 geographic sources of hardwoods. Due to the acreage and values involved, we decided to select from the mountain sources first. The mountain sources of hardwoods are:

Arkansas - Ouachita and Ozark National Forests

Kentucky - Daniel Boone National Forest

Northern Appalachians - George Washington and Jefferson National Forests, except the Clinch and Holston Districts

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[1] The author is the Tree Improvement Forester for the National Forests of the Southern Appalachians stationed with the U. S. Forest Service in Asheville, N. C.

Central Appalachians - Clinch and Holston Districts of the Jefferson National Forest, Cherokee National Forest north of the Little Tennessee River, and the Pisgah National Forest north of Asheville

Southern Appalachians - Nantahala and Chattahooche National Forests, and the Pickens District of the Sumter National Forest

The remainder of the Region was divided into six sources of hardwoods, of which five would provide bottomland types. We plan no selections from these sources at present:

North Alabama Mississippi - Talladega, Bankhead, Holly Springs, Tombigbee, Bienville, and St. Francis National Forests

West Gulf - Sabine, Angelina, Sam Houston, Davy Crockett, Kisatchie, Homochitto, and Desoto National Forests

East Gulf - Conecuh, Apalachicola, Osceola, and Ocala National Forests

Delta - Delta National Forest

Piedmont - Oconee, Sumter (excluding Andrew Pickens), and Uwharrie National Forests

East Coast - Francis Marion and Croatan National Forests.

SPECIES SELECTION

The selection of a species to be included in the program was based on three factors: (1) Acreage occupied by the species; (2) present value; and, (3) opportunity to make selections of high quality trees of that species. All factors were considered in every selection.

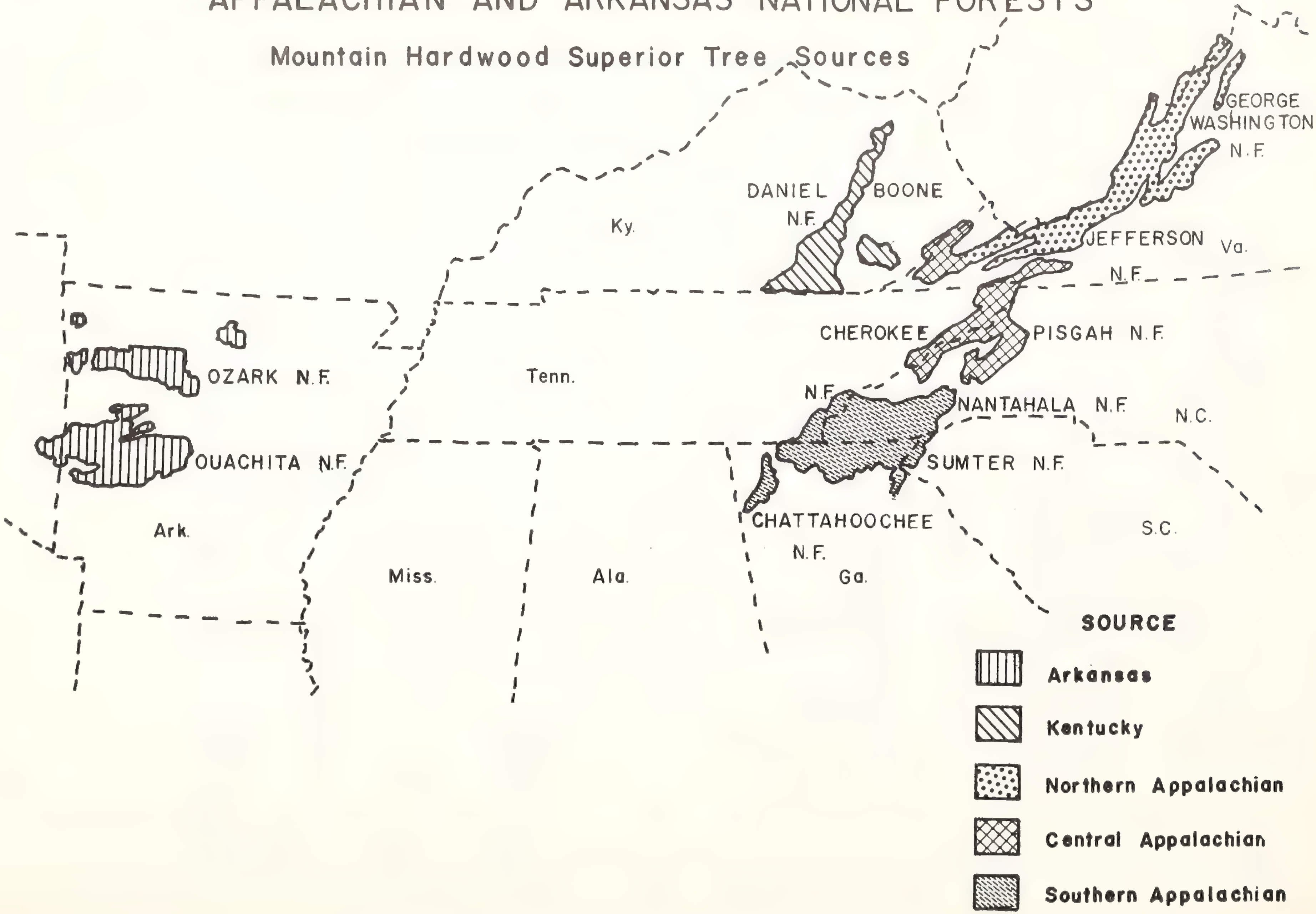
Black walnut, is a high value species with a wide range but with a limited possibility for providing high quality selecting in National Forest lands.

This species will be part of future stands, but we are not including it in our present Tree Improvement Program.

The present program is concerned with the selection of white oak (Quercus alba L.), red oak (Q. rubra L.), black oak (Q. velutina Lam.), chestnut oak (Q. prinus L.), yellow-poplar (Liriodendron tulipifera L.), and black cherry (Prunus serotina Ehrh.)

APPALACHIAN AND ARKANSAS NATIONAL FORESTS

Mountain Hardwood Superior Tree Sources



The species by sources are as follows:

Arkansas - black oak, red oak, and white oak

Kentucky - black oak, chestnut oak, red oak, white oak, and yellow-poplar

Northern Appalachians - black oak, chestnut oak, red oak, white oak, black cherry, yellow-poplar

Central Appalachians - black oak, chestnut oak, red oak, white oak, black cherry, yellow-poplar

Southern Appalachians - black oak, chestnut oak, red oak, white oak, black cherry, yellow-poplar

INDIVIDUAL TREE SELECTION

Selection procedures require recording the growth rate of all trees by 10-year increments, measuring the basal area of the stand with the selected tree as the plot center, and recording the elevation, aspect, and slope of each selected tree.

The selection of individual trees is based on criteria developed from research and observations. To be acceptable, each candidate tree must meet the following basic requirements:

Straightness - A straight line from the center of the merchantable top to the edge of the stump, through the inside of the sweep, must stay within the bole. Crooks which are mechanical may be disregarded.

Grade - A grade I first log and at least a grade II second log must be available.

Damage - Trees must be free from insects or disease; fire or mechanical damage will be allowed.

Grain - Spiral or interlocking grain cannot be in evidence.

Flowers - Ability to produce fruit must be proved.

After the above requirements are met, each species must undergo specific comparisons within its genera, as follows:

Yellow-poplar is compared to the 3-5 closest dominant yellow-poplar trees on the same site. The candidate tree must be free from epicormic branches in all but the last 16 feet of the merchantable bole. Volume of the candidate tree must be equal to or greater than the volume of the average comparison tree. The comparison trees cannot be less than one year younger, or if possible, not more than three years older than the candidate tree. Pruning of the candidate tree is compared to the adjacent stand, and total height of the candidate tree is compared with total height of the average comparison tree; point ratings are given for each characteristics.

Oak Species are compared with the 3-5 closest dominant oak trees on the same site. The comparison trees cannot be less than five years younger or generally not more than five years older than the candidate tree. Using the methods of Doolittle (1958) and Olsen and Della-Bianca (1959) it is possible to compare the heights of different oak species. Site index of the candidate tree is compared to the average site index of the 3-5 comparison trees and a point rating is then given. The candidate tree must have an apical dominance equal to 60 percent of the site index for the tree. No trees are accepted which have epicormic branches on the first log, but they may be present above the first log.

Eighty percent of the merchantable bole must be free from dead branch stubbs. From methods by Trimble (1960), a comparison of the annual diameter growth rate for the last 20 years is made between the average comparison tree and the candidate tree. This is done by converting all growth rates to the red oak growth rate and giving a point score.

Black Cherry. No comparison trees are used in rating black cherry. To be acceptable, the tree must have an apical dominance equal to 60 percent of the site index for that tree. The average annual diameter growth rate is taken for the past 20 years, compared to a growth rate table, and a point score given. As with the oak species, no epicormic branches are allowed on the first log, but they may be present on the remainder of the bole.

CLONAL BANK

All approved superior trees will be incorporated into a clonal bank to prevent loss of the clone. We do not plan to establish a hardwood seed orchard at the present time, because we haven't solved the problem of converting hardwood stands of one species to stands of another hardwood species.

In the establishment of the clonal bank, we hope to grow hardwoods on their own roots, by rooting cuttings. Work by McAlpine (1964), Kormanik and Porterfield (1966), and Farmer[2] indicates that rooting of cherry and yellow-poplar cuttings is possible. With the oaks it may take longer to develop a process for rooting cuttings.

From my grafting work with white oak, red oak, and chestnut oak, I believe that if we cannot root oak cuttings we can establish a grafted clonal bank for them.

These clonal banks will be established in Arkansas and North Carolina. The Ouachita Seed orchard, presently a pine orchard, will be used to establish the hardwood clonal bank for the Arkansas source. The Beech Creek Seed orchard, also a pine orchard, will be used for the hardwood clonal banks for the Appalachians and Kentucky.

In establishing the clonal banks, we will have 30 clones of each species from each geographic source. This will be 90 clones for Arkansas, 150 for Kentucky, and 540 for the Appalachians, a total of 780 clones.

The clonal bank will be established at 20 by 20-foot spacings. This will give enough room for ramet development and will be an excellent source of vegetative material for seed orchard establishment, when needed.

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[2] Farmer, R. E., Jr., and Hall, G. C. Mist Propagation of Black Cherry Cuttings. Unpublished manuscript, 1970.

LITERATURE CITED

Doolittle, W. T. 1958. Site index comparison for several forest species in the Southern Appalachians. Soil Sci. Soc. Amer. Proc. 22(25): 455-458

Kormanik, P. P. and Porterfield, E. J. 1966. Rooting Yellow-poplar Cuttings - Forest Farmer 26(2): 24, 41-42

McAlpine, R. G. 1964. A Method for Producing Clones of Yellow-poplar - J. Forest. 62: 115-116

Olsen, D. G. and Della-Bianca, L. 1959. Site index comparisons for several tree species in the Virginia-Carolina Piedmont. Southeastern Forest Exp. Sta., U. S. Forest. Serv., Sta. Pap. 104, 9 p.

Trimble, Jr., G. R. 1960. Relative diameter growth rates of five upland oaks in West Virginia. J. Forest. 58: 111-115

USES OF HARDWOOD CLONES IN FORESTRY RESEARCH

Paul P. Kormanik and Robert G. McAlpine[1]

Clones of forest trees can be of considerable value as research tools. Furthermore, for high valued species or specific products or for special use, planting vegetative propagules may be more desirable and perhaps more economical than planting seedlings. Horticulturists have for years used clones to increase production and to improve the quality of a variety of fruits and ornamental plants. The use of hardwood clones in forestry is not, of course, a new concept. Poplar has been managed and propagated for a long time in Europe (Schreiner 1959) and great strides have been made in the same direction throughout the southern central United States with cottonwood (Mohn, C. A., W. K. Randall, and J. S. McKnight 1970). However, the use of poplar or cottonwood clones has been rather restrictive in that they produce well on only exceptionally fertile land and thus growth rate is the single most important selection criterion (McKnight 1970). The primary reason perhaps for the use of so few hardwood species as clones in forestry in the past was that so few commercially important hardwoods could be vegetatively propagated. Recent advances in both the art and science of rooting cuttings from forest trees has made it feasible to put clonal lines into specialized uses.

As researchers, you can readily see the advantage of having clonal lines of selected trees growing on their own root systems and available for use in seed orchards, fertility studies and in studies pertaining to disease and drought resistance. However, more important than the specialized use of clones in specific physiological or genetic studies is their potential use to gain a better understanding of the biological mechanisms of species adaptability. At the Forestry Sciences Laboratory and at the School of Forest Resources in Athens, Ga., we have been working on a small scale in using vegetatively propagated materials of several species for about 10 years. The investigations were initiated when McAlpine (1964) successfully propagated yellow-poplar and then expanded his procedure to other species. Some of his original yellow-poplar clones have been propagated on a small scale continuously since 1962 and have provided numerous leads that indicate the potential of clones in forestry research.

SPECIES ADAPTABILITY

What, here, is meant by "species adaptability"? Species adaptability most surely would include those environmental adaptations mediated by the photo-periodic or temperature regimes by which races are recognized: these intra-specific adaptations are accepted and are well documented. However, species adaptability can be more specific than that recognized in races or even varieties, and is encountered in all phases of forestry. It is perhaps best exhibited in the ability of a species to adapt and compete successfully over a wide range of site conditions. Few hardwoods are so restrictive in their site requirements that they make suitable growth only in a narrow range of environmental conditions. Thus, while hardwoods grow best on certain sites such as well-drained bottomlands and coves, they also make suitable growth on other sites. A forester does not go into the woods many times before he encounters a given hardwood species growing "off-site" and making respectable growth: from an infinite number of such observations probably arose the concept of "soil-site studies." For years, with limited success, we have attempted to measure soil and other site variables and put limits on a species growth potential based upon measurable environmental factors. Variability in soil properties has been uniformly encountered in these studies and to this item has been attributed our ability to correlate only gross site characteristics to tree growth (Mader, 1963; Ike and Huppuch, 1968; Kormanik, 1966; and Trimble and Weitzman, 1956). It is easy to blame soil variability--which is so well documented--for our failure to obtain both practical and workable equations for predicting growth but it is short-sighted for it stresses soil variability and thus ignores the importance of species adaptability. Thus, while the limiting factor for assessing growth potential may not be soil variability but rather species adaptability, the latter has received little attention. Some earlier workers (Büsgen and Münch, 1929) recognized such adaptation under the broad headings of "local physiological and soil races." It is possible that with species that adapt to a wide range of sites, we may be able to identify and propagate varieties for planting on specific sites.

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[1] The authors are, respectively, Research Forester and Principal Silviculturist, Forestry Sciences Laboratory, Southeastern Forest Experiment Station, Forest Service, U. S. Department of Agriculture, Athens, Ga.

PATHOLOGY

One of the potential uses of clonal lines is in the field of forest diseases. Vegetative propagules are ideally suited for studies to determine susceptibility to root pathogens and for development of control measures. In fact, among the five yellow-poplar clones propagated at Athens one was highly susceptible to attack by _Fusarium_ _solani_. Progressive dying among large numbers of ramets of this clone enabled the disease to be observed in early and late stages of decay. Possible uses of this specific clone are in pretesting for the presence of _F_. _solani_ in planting sites and in observing rate of spread of the pathogen from spot inoculations.

PHYSIOLOGY AND MORPHOLOGY

Another potential use of clones in forest research is in correlating morphological adaptations with physiological responses. Through investigations in this broad area, mechanisms responsible for species adaptatibility can be found. While randomly selected clones will yield information among species, careful selection of individuals from specific sites will be needed to establish intraspecific differences. We are making such selections now but most of our studies have included only clones propagated from random selections.

Elongating root tips probably have the highest respiration rate of any tree organ (Kramer and Kozlowski, 1960) and the ability of roots to carry on this process favorably under a range of soil conditions would be a potential asset. Root respiration rates seem to vary among species (Kramer and Kozlowski, 1960) and Steinbeck and McAlpine (1966) using root tips from four clonal lines of four species found significant respiration rates among all four species: significant inter-clonal rates were measured in only one species, black willow. Unpublished work from the Forestry Sciences Laboratory with randomly selected clones of sycamore and yellow-poplar has revealed no significant clonal differences and little relationship between root respiration and clonal growth rate.

As alternate uses for the fertile bottomlands take precedence over growing trees, production of hardwoods on upland sites becomes more and more a reality. This means that species best adapted to moist coves and bottomlands must grow on drier sites. Recently some of our original yellow-poplar clones were used in a study to determine the feasibility of using potted plants to determine adaptability to a range of moisture stress from very wet to very dry. In this case, all clonal lines rapidly succumbed to flooding within seven days. The same clones were kept under a minimum watering schedule and again all clones faired badly with the faster growing clones wilting back more rapidly than the slower growing ones. No significant intra-clonal differences were detected, but some differences in formation of the casparian strip in response to drought was apparent within 5 cm of the root tip.

In studies to determine adaptability within and among species, anatomical investigations of roots will be needed with special consideration given to the endodermis and its casparian strip. Studies involving three species--swamp tupelo, yellow-poplar and American sycamore--revealed some interesting differences in internal structure of the roots. Seedlings of swamp tupelo growing in a well drained medium readily developed a well-differentiated endodermis with distinct casparian strips in the 2 cm root tip segments examined, but in a flooded medium the endodermis was poorly organized and the casparian strips were not present (Hook et al., 1971). In a similar study with yellow-poplar clones, flooded roots decomposed so rapidly that histological examination of roots was not possible. However, roots of yellow-poplar ramets not flooded and others from which water was withheld had well differentiated endodermis with prominent casparian strips. Yellow-poplar does not normally survive in nature under flooded conditions.

In other exploratory work we found that sycamore, which is intermediate in flood tolerance between the very tolerant swamp tupelo and intolerant yellow-poplar, exhibited endodermal development different from either of the above: the cells of its endodermis were occluded with a substance that exhibited a bright yellow color when the root tips were stained with safranin and fast green. With sycamore, the casparian strips were not nearly as prominent as in yellow-poplar although the endodermis was more highly developed. Thus, superficial work among just three species, whose site requirements differ, revealed three distinctly different patterns of endodermis specialization. It seems likely that some degree of species adaptability may hinge on changes in properties of cells making up the endodermis.

Nutrient requirements and response to natural and artificial fertility regimes are other areas of study for which clones may be ideally suited. With this type of work the objectives of the study will to a great extent dictate the care which must go into ortet selection. Steinbeck 2/ in a greenhouse study was able to show some intra-clonal response of random yellow-poplar clones to different concentrations of a basic Hoagland nutrient solution. Unfortunately, there was complete uniformity in the clones' susceptibility to a sudden white fly and aphid infestation and the study came to a premature end. Recently, however, Steinbeck (1971) used the same approach with randomly selected clonal lines of sycamore with good results. He reported intra-clonal differences in branching characteristics as well as in dry matter production and height growth. He concluded that a search for nutritional varieties should be fruitful.

Planting ramets in pots for intensive testing may be the first step in ascertaining the desirability of specific lines, but it may also be quite feasible to select desirable clonal lines by simply comparing the propagules after they have over-wintered in the transplant beds. An example of this was reported by Steinbeck and Kormanik (1968) with two clones of yellow-poplar. In this case, the root system of one clone was consistently larger than cuttings of another rooted at the same time. After one year in a field planting, the clone with the larger root system outgrew the smaller one in every characteristic measured. Furthermore, four years after planting, the faster growing clone still maintains this advantage. 3/

The afore mentioned examples are a few of the instances in which the availability of clones in research has proved helpful. Perhaps in the not too distant future continued work in vegetative propagation will make possible the clonal testing of our selections over a wide range of soil and site conditions years before the first progeny are available from seed orchards.

2/ Personal communication, Dr. Klaus Steinbeck, Assistant Professor, School of Forest Resources, University of Georgia, Athens.

3/ Steinbeck, Klaus, George D. Kessler and Paul P. Kormanik. Root and shoot development of two clones of *Liriodendron tulipifera* L. four years after planting. In Process.

LITERATURE CITED

Büsgen, M., and Münch E. 1929. The structure and life of forest trees. John Wiley & Sons, Inc., New York. 436 p.

Hook, Donal D., Claud L. Brown and Paul P. Kormanik. 1971. Inductive flood tolerance in swamp tupelo (Nyssa sylvatica var. biflora (Walt.) Sarg.). J. Exper. Bot. 20(70): 78-89.

Ike, Albert F., Jr., and C. D. Huppuch. 1968. Predicting tree height growth from soil and topographic site factors in the Georgia Blue Ridge Mountains. Ga. Forest Res. Counc. Pap. 54, 11 p.

Kormanik, Paul P. 1966. Predicting site index for Virginia, loblolly and shortleaf pine in the Virginia piedmont. Southeast. Forest Exp. Sta., U. S. Forest Serv. Res. Pap. SE-20, 14 pp., illus.

Kramer, P. J., and Kozlowski, T. T. 1960. Physiology of trees. McGraw-Hill Book Co., Inc., New York. 642 p.

Mader, D. L. 1963. Soil variability - a serious problem in soil-site studies in the Northeast. Soil Sci. Soc. Amer. Proc. 27: 707-709.

McAlpine, Robert G. 1964. A method for producing clones of yellow-poplar. J. Forest. 62(2): 115-116.

McKnight, J. S. 1970. Planting cottonwood cuttings for timber production in the South. South. Forest Exp. Sta., U. S. Forest Serv. Res. Pap. SO-60.

Mohn, C. A., W. K. Randall and J. S. McKnight. 1970. Fourteen cottonwood clones selected for midSouth timber production. South. Forest Exp. Sta., U. S. Forest Serv. Res. Pap. SO-62.

Schreiner, Ernst J. 1959. Production of poplar timber in Europe and its significance and application in the United States. U. S. Department of Agric. Handbook 150. 124 pp.

Steinbeck, Klaus, and Robert G. McAlpine. 1966. Inter-and intra-specific differences in the root respiration rates of four hardwood species. Forest Sci. 12: 473-476.

Steinbeck, Klaus. 1971. Growth responses of clonal lines of American sycamore growth under different intensities of nutrition. Can. J. Bot. 49(3): 353-358.

Steinbeck, Klaus, and Paul P. Kormanik. 1968. First-year root system development of two clones of yellow-poplar. Ga. Forest Res. Counc. Pap. 55, 4 pp.

Trimble, G. R., Jr., and S. Weitzman. 1956. Site index studies of upland oaks in the northern Appalachians. Forest Sci. 2: 162-173.

SOME ANATOMICAL ASPECTS OF ROOTING QUAKING ASPEN [1]

by

Ray R. Hicks, Jr. [2]
and
William T. Gladstone [3]

Abstract

Aspen root suckers and stem cuttings consisting of the current year's growth from trees 1, 2, 3 and 4-10 years old were collected for microscopic examination. Preformed root primordia were not observed in aspen cuttings. Root sucker cuttings developed roots from interfascicular regions of the stele or in association with phloem rays. Cuttings from the 1, 2, 3 and 4-10 year age classes failed to develop root primordia when placed in conditions favorable to rooting of sucker cuttings. Thus it was concluded that reduced rooting in physiologically mature aspen cuttings resulted from

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[1] Part of a thesis submitted to the Graduate Faculty of the State University College of Forestry at Syracuse University in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

[2] Assistant Professor of Forestry, Stephen F. Austin State University, Nacogdoches, Texas.

[3] Assistant Professor of Silviculture, State University College of Forestry at Syracuse University, Syracuse, N.Y.

the inability to form primordia rather than mechanical restriction of roots already formed.

Introduction

Quaking aspen (*Populus tremuloides* Michx.) stem cuttings from juvenile root suckers are easily rooted, but cuttings consisting of the current season's stems from physiologically mature trees are difficult to root. Two factors which could account for reduced rooting are lack of preformed root primordia in mature stems and mechanical obstruction of existing primordia. These anatomical factors were examined in mature stems as well as in rooted juvenile aspen cuttings.

Literature Review

Many living cells in plants are capable of dedifferentiation and subsequent organization into adventitious structures. However, adventitious roots in cuttings usually originate from specific loci within the anatomical configuration of the stem. *Salix fragilis* stems contain preformed root primordia which are associated with phloem rays of leaf gaps (Carlson, 1950). Preformed root primordia arise from the cambial zone in stems of *Populus deltoides* and *P.* x *euramericana*, but the difficult-to-root European aspen (*Populus tremula*) contains no preformed root primordia (Ruggeri, 1966).

Stems of many species contain no preformed root primordia; in such stems roots may develop after the cuttings are excised. Mahlstede and Watson (1950), found that root primordia originate from the cambium of Vaccinium cuttings. Roots arise from phloem ray tissue of juvenile Hedera helix stem cuttings and from phloem ray and basal callus tissue in mature cuttings of the same species (Girouard, 1967a, 1967b).

Mechanical restriction of root primordia has been implicated as a cause of reduced rooting. Nanda, Anand and Kumar (1969) observed thicker bands of fibrous tissues surrounding the stele in species which root poorly. According to Breakbane (1961), apple and pear varieties which are difficult to root contain more continuous rings of sclerenchymatous tissue than easily rooted varieties. However, mechanical restriction was not proposed as the only cause of reduced rooting since difficult rooting plants failed to produce root primordia. Mature Hedera helix stems contained thicker fibrovascular caps in the cortex than juvenile stems, but these structures caused no apparent restriction of root penetration (Girouard, 1967b). Sachs, Loveti and Debie (1964) compared the rooting potential of several olive, cherry and pear cultivars with the density and continuity of sclerenchyma in the cortex. They found no obvious relationship and concluded that rooting ability was dependent on factors controlling differentiation of root primordia rather than mechanical restriction of roots already formed.

Materials and Methods

Cuttings for examination were consistently collected from the current flush of stem growth and age classes were assigned according to the age of the parent tree. Thus an age class is defined as the current year's stem growth from a tree "n" years of age. Cuttings which were produced by burying aspen root segments in moist vermiculite and allowing them to sprout in the greenhouse were designated age class "root sucker" (RS).

Stem segments were fixed in formalin-aceto-alcohol (FAA) directly after collection to investigate the possibility of preformed root primordia in aspen stems. Two cuttings each from the age classes RS, 1, 2, 3 and 4-10[4/] were prepared for microscopic examination by standard techniques. Twenty cuttings each from age classes 1, 2, 3 and 4-10 were examined macroscopically after removing the cortex. Ruggeri (1966) observed root primordia in Populus deltoides stems using this technique. The basal one half inch of two cuttings each from age classes RS, 1,

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[4/] Cuttings were collected from trees ranging in age from 4 to 10 years.

2, 3 and 4-10 was sectioned and examined microscopically after the cuttings had been in sand rooting medium for 33 days under ambient greenhouse conditions.

Groups of 40 root sucker cuttings were rooted in distilled water under controlled environmental conditions to investigate the root forming process. The growth chamber was maintained at 68° F and illuminated at 431 fc for a 14 hour photoperiod. Visible roots appeared after 5 days. Ten cuttings were removed at intervals of 3, 5, 7 and 14 days and the basal half inch was fixed in FAA. To further investigate the possibility of preformed root primordia in root sucker stems, half inch basal segments from 20 root suckers were fixed and examined directly after removal from the parent roots.

Results

Preformed root primordia were not observed in any age class when examined either macroscopically or microscopically.

Cuttings from trees of increasing age were characterized by increasing numbers of sclerenchymatous cells in the cortex (fig. 1 A, B, C, D). However, neither sclereids nor phloem fibers formed a closed ring around the stele.

Root primordia were observed only in root sucker cuttings among those which had remained in rooting medium.

Root primordia were observed microscopically in sucker cuttings after 3 days in the control room (fig. 2 A, B), and primordia were well developed after 5 days (fig. 2 C). Many roots had penetrated the epidermis after 7 days (fig. 2 D, F).

Apical growth of aspen stems results in the formation of dictyosteles with vascular bundles encircling the pith (fig. 2 B). Activity of the cambium rapidly closes the interfascicular regions resulting in a continuous siphonostele (fig. 1 A, B, C, D; 2 A, C). Root sucker cuttings with either stelar configuration were capable of rooting (fig. 2 A, B, C, D). Adventitious roots develop in the interfascicular regions of stems in the primary state of growth (fig. 2 B) and in association with ray cells after cambial activity has occluded the interfascicular regions (fig. 2 A, C, D). Root primordia differentiate from the cambium or cambial derivatives toward the phloem in these interfascicular or ray areas (fig. 2 A, E).

Conclusions

Preformed root primordia are not an important source of adventitious roots in either juvenile or mature quaking aspen cuttings.

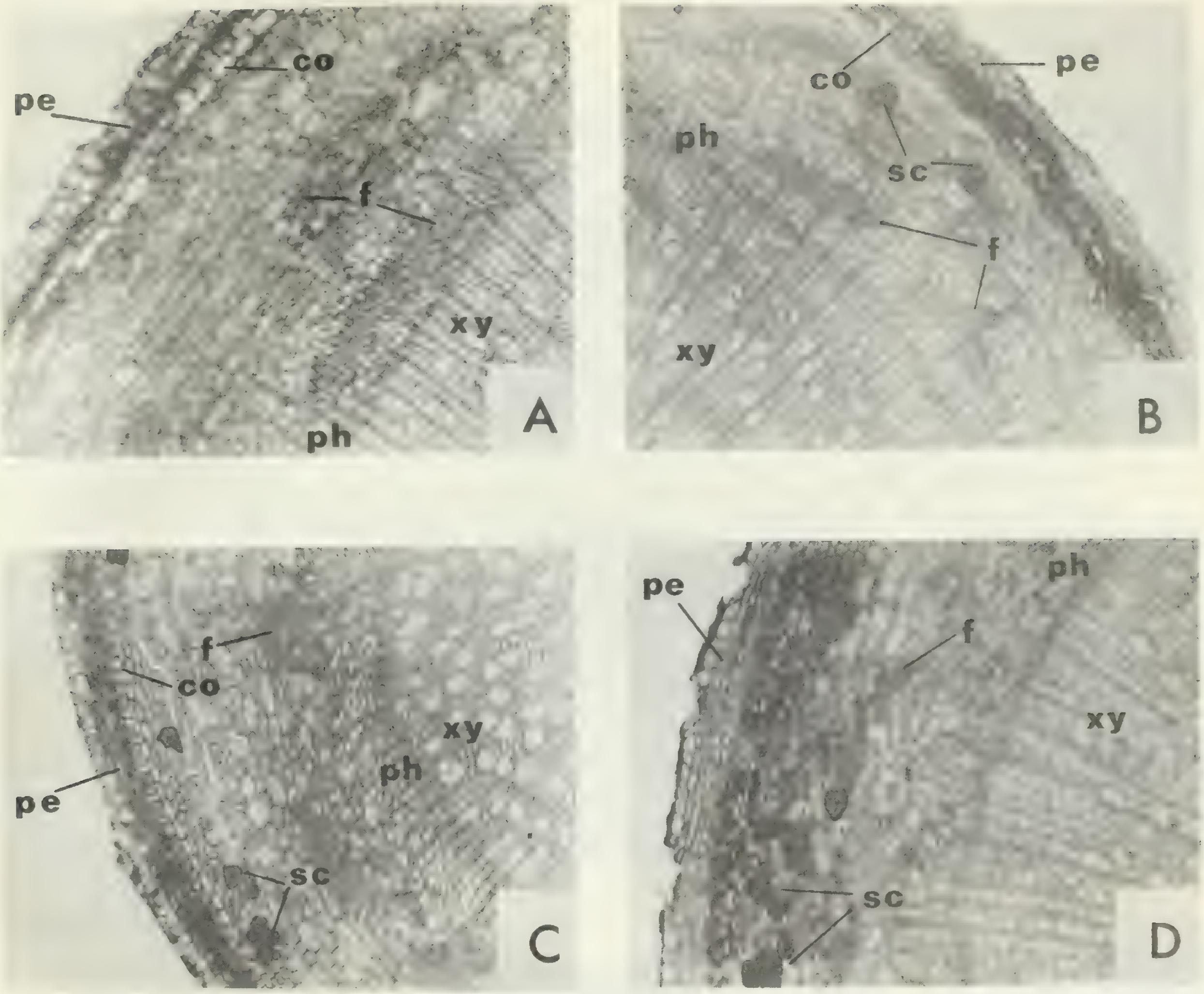

Figure 1. Cross sections of current year aspen stems from trees of varying age classes

(A) stem from the one year age class with well developed periderm (X 50). (B) two year age class stem with collenchymatous layer apparent (X 50). (C) stem from the three year age class with sclereids apparent in the cortex (X 50). (D) stem from the 4-10 year age class illustrating the abundance of sclerenchymatous cells in the cortex characteristic of this age class (X 50).

Legend:
ph - phloem
xy - xylem
pe - periderm
f - phloem fibers
co - collenchyma
s - sclereids

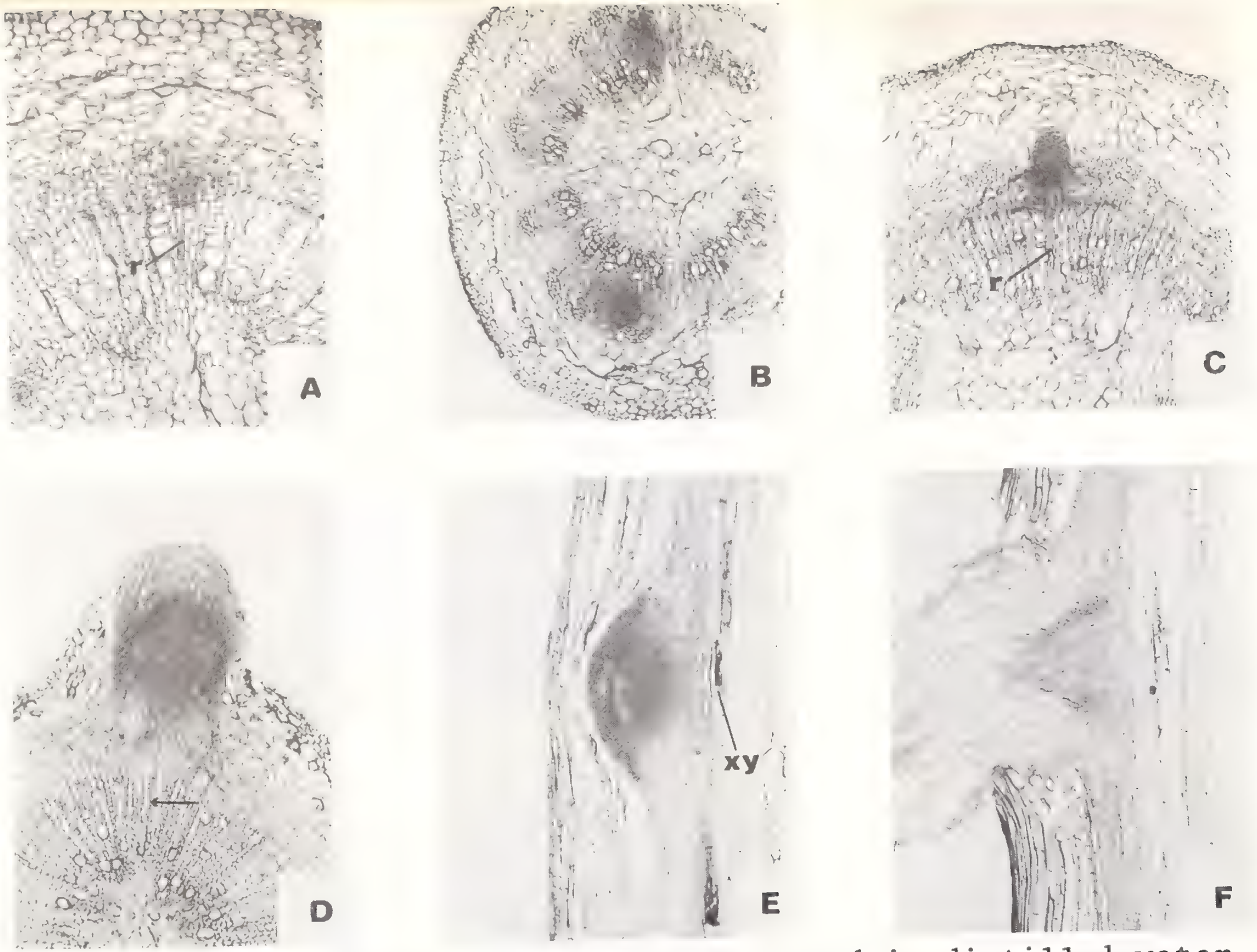

Figure 2. Root formation in sucker cuttings rooted in distilled water

(A) cutting after three days indicating association of root primordium (cells with dense cytoplasm) with ray (X 75). (B) cutting after three days showing primordia differentiating in interfascicular regions (X 60). (C) stem after five days illustrating association between root primordium and ray (X 60). (D) stem after seven days--arrow indicates ray from which the primordium probably originated (X 60). (E) longitudinal section of root sucker cutting after seven days showing the primordium in juxtaposition with the cambial zone (X 60). (F) longitudinal section of a root sucker cutting after seven days with a fully developed root (X 60).

Legend:

r-ray
xy-xylem

Figure 2

BREEDING TECHNIQUES FOR WHITE OAK

F. Thomas Ledig, James W. Beland IV, and John H. Fryer[1]

Because it is a major species on vast acreages in the Eastern United States, many organizations are considering improvement programs for white oak (Quercus alba L.). Such programs will require information on techniques for breeding, and particularly on extraction and storage of pollen and controlled pollination. This paper describes a series of limited trials in which some techniques for breeding white oak were developed.

Sharp and Chisman (1961) described morphological development of staminate flowers, and Sharp and Sprague (1967) described stages in pistillate flowering, acorn development, and the influence of weather factors on seed yield. Individual white oak trees normally shed their pollen before the female flowers are receptive (Sharp and Chisman 1961; Sharp and Sprague 1967; Irgens-Moller 1955). Maximum receptivity in a variety of oaks pollinated by Piatnitsky (1960) was 3 to 5 days after anthesis of the staminate flowers. Sharp and Sprague (1967) reported that white oak flowers with separate, elongate-reflexed styles and the inner surface of the stigma reddish to reddish-yellow appear to be receptive. Williamson (1966) observed a great deal of acorn abscission between the times of pollination and fertilization.

Controlled pollinations have been reported by Piatnitsky (1960), Ness (1918), Wright (1953), and Schreiner and Duffield (1942). No accounts have been found of controlled pollinating oak flowers in viscose sausage casings, which permit the passage of light, water, and air but not contaminating pollen. Interspecific hybrids from controlled pollinations have been produced by Ness (1918), Schreiner and Duffield (1942), and Piatnitsky (1960).

METHODS

Controlled Pollination

In New Haven, Connecticut, three large, fruitful, open-grown white oaks were chosen, and emerging shoots were emasculated and bagged on May 4 and 5, 1968. By removing most leaves without pistillate inflorescences in their axils it was possible to include several shoots in each bag. The number of stems bearing female flowers, as well as the number of inflorescences and flowers per stem, were recorded for each bag. Only flowers with exposed stigmata were tallied. Most inflorescences had one or more spherical bodies which were assumed to be flowers that had not developed normally. These exhibited no evidence of an ovarial opening or stigmatic surface and were often on the extreme distal tips of flower stalks.

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[1] F. T. Ledig and J. H. Fryer are members of Yale University, School of Forestry, New Haven, Connecticut. J. W. Beland is Associate Plant Geneticist at the Institute of Forest Genetics, Southern Forest Experiment Station, Forest Service, USDA, Gulfport, Mississippi. The research was carried out under cooperative agreement between the two agencies.

Depending on the tree, the peak of anthesis occurred on May 12, 13, or 14. Catkins were collected between May 8 and 13. Pollen was extracted by shaking and sieving after overnight drying in the laboratory. For interim storage, the pollen was refrigerated in closed vials.

Germination was tested 1 week after collection. After 93 hours at 27° C., germination of a polymix of three trees ranged from 18 to 25 percent. In another test, however, only 5 percent of pollen from one of these trees germinated compared to 45 and 64 percent germination from the others. Hence, the polymix probably represented two individuals.

To define the time of receptivity, a different series of five bags on each tree were pollinated every day for 5 days (a total of 25 bags per tree). Because it was uncertain whether every flower of a given inflorescence reached the stage of receptivity at the same time, the efficiency of multiple pollination was also tested. One series of five bags on each tree was pollinated every day for 5 days (a total of five bags per tree). For controls, one series of five bags on each tree was left unpollinated and one series of five branches was left unbagged for wind pollination.

Pollinating was done during the morning hours beginning the third day after anthesis. Pollen was applied generously with a brush because it was somewhat sticky.

Tops of the bags were cut away on June 1, about 2 weeks after anthesis. The bases of all bags and twigs proximal to them were sprayed with Bird Tanglefoot, a sticky repellent substance, to discourage birds, squirrels, and other predators. Branches were also sprayed with DDT to eliminate a scale insect infesting one study tree.

Branches were inspected on July 3 and on August 18, before acorn maturity, to determine whether abscission had occurred. On August 19 the branches that still bore developing acorns were enclosed in aluminum screening wire to protect against squirrels and birds and prevent loss of acorns at maturity. By August 1 squirrels had been observed eating green acorns, which had scarcely begun to enlarge. Acorns were collected on September 12, weighed individually, and sown immediately in a mixture of soil, peat, and sand in a greenhouse. Germination was recorded 2 months later.

The relationship between premature abscission and cytological development after controlled and wind pollinations was studied in southern Mississippi in 1968. Two trees were control-pollinated by the methods described above, except that pollinations were made with an aspirator. Immature acorns were collected during the growing season, but enough (one-third) matured to compare success of controlled and wind pollination.

Gibberellin Effect

The procedure of germinating pollen on artificial media is an important one, because a great deal of effort can be wasted if pollinations are made with inviable pollen. Germination, while not guaranteeing that the pollen is capable of fertilization, does provide some indication of viability. Gibberellins accelerated the rate of germination of pollen of Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] as shown by Ching and Ching (1959) but had no effect on pollen of *Pinus mugo* in trials reported by Nygaard (1969).

Because Hart (unpublished data) demonstrated that gibberellic acid increased pollen germination in oaks, the effect of GA_7 was tested in a factorial experiment with three levels of sucrose, 0, 5, and 10 percent, and four levels of GA_7, 0, 100, 200, and 300 ppm, in distilled water. Each treatment was replicated twice. All media were autoclaved. Freshly collected pollen was dusted over a drop of the media on a slide, and incubated as a hanging drop culture in a van Tiegham cell at 27° C. in darkness.

Counts of pollen germination and measurements of pollen tube growth were made approximately 2, 8, 11, 34, 46, and 96 hours after initiation of the trial; by 96 hours, germination and tube growth appeared to have ceased.

Pollen Storage

Storage of pollen for up to 2 months would enable crosses of later-blooming northern trees with pollen from those further south, and storage for 1 year would permit crossing early-blooming trees with pollen of late-blooming trees in any region. Viability can be maintained in many species at particular temperatures and humidities, and freeze-drying has also been successful with some species. Both methods were tried. Viability of stored pollen was tested *in vitro* (germination on artificial media) and *in vivo* (actual fertilization as shown by seed set).

Pollen was collected from three trees at the beginning of anthesis. It was extracted by shaking and sieving after drying overnight. After storage for 6 to 8 weeks in the refrigerator, the pollen was divided for tests of the two types of storage methods.

In the first, several relative humidities were tested for storage at 2° C. The humidities were achieved by placing pollen in dessicators containing saturated salt solutions. The salts were potassium acetate, calcium chloride, calcium nitrate, and sodium chloride. At equilibria the relative humidities above saturated solutions of these salts are 23.5, 40, 65, and 75 percent, respectively. A stirrer whose shaft extended through the top of each dessicator turned a fan to eliminate humidity gradients. Pollen samples from each of the three trees were kept separate and considered as replicates.

Freeze-drying was tested on pollen from a single tree. The experiment included, factorially, two pretreatments, prefrozen or not prefrozen; two methods of storage at -5° C., under nitrogen or under vacuum; and three periods of evacuation, 10, 30, or 60 minutes on the freeze-dry apparatus. In the prefreezing treatment, the temperature of the pollen was lowered to -80° C. for about 15 seconds in an acetone-dry ice bath prior to freeze-drying. Ampules containing pollen were sealed with a propane torch after evacuation and while still attached to the freeze-dryer. For vacuum storage, the ampules were sealed while under the original vacuum; for nitrogen storage, dry nitrogen gas was admitted to the ampules through the freeze-drying manifold.

For the humidity tests germination was scored after 70 days and after 295 days of storage. For the freeze-dry series, germination was counted only after 300 days of storage. The germination medium was 2 percent agar, 5 percent sucrose, and 0.01 percent boric acid. Incubation was in the dark at 22° C. between microculture slides sealed together to prevent dehydration. All materials were autoclaved before dusting the pollen on the medium. After incubation for 18 to 24 hours, germination was scored as the number of grains with pollen tubes longer than the width of the grain. Results were expressed as a percentage of the 100 counts from two randomly selected fields under a 10X microscope. After arc sine transformation, the data were subjected to analysis of variance.

To test the effectiveness of the pollen, it was applied to bagged female flowers on two trees. Techniques were identical to those described earlier. On each tree, 40 branches bearing female flowers were bagged about 4 days before anthesis, on May 10 and 11, 1970. Anthesis occurred on May 15 and 16. Pollinations were made on May 20 and 21, and bags were removed on June 6. Because of the scarcity of stored pollen, every storage treatment was not represented in the pollinations. Controls consisted of pollinations made with fresh pollen of the same tree as that used in the storage trial and of bagged unpollinated branches.

All statistical tests were done at the 0.05 level of probability.

RESULTS AND DISCUSSION

Controlled Pollination

The viscose bags proved effective. No acorns were set on the 12 bagged, unpollinated branches which survived accidents until fall. The percentage of seed sets from controlled pollinations was 23.6 compared to 7 for wind pollinations. Additionally, 2.1 acorns per bag were collected from controlled pollinations but only 0.8 from wind pollinations (table 1).

Table 1.--Results of controlled and wind pollinations in Connecticut, 1968

Item and unit of measure	Controlled pollination tree				Wind pollination tree			
	A	B	C	Total	A	B	C	Total
Branches bagged (No.)	24	27	20	71	3	5	4	12
Branches setting seed (No.)	19	16	9	45	0	3	3	6
Flowers (No.)	271	182	172	625	33	60	33	126
Acorns (No.)	86	43	19	148	0	6	3	9
Seed set (Pct.)	31.7	23.6	11.0	23.6	0	10.0	10.0	7.0
Acorns/branch (No.)	3.6	1.6	1.0	2.1	0	1.2	0.8	0.8

There was no difference in the success of single pollinations made from 3 to 7 days after anthesis (table 2). Apparently the period of receptivity lasts for at least 7 days after anthesis, and pollination at any point during this period should be successful.

Table 2.--Yield of mature acorns by date of pollination and by tree

Days from anthesis to pollination	Tree			
	A	B	C	Mean
	----- Acorns/flower -----			
3	0.33	0.31	0.07	0.25
4	0	.22	.08	.14
5	.26	.24	.13	.23
6	.25	.10	.17	.28
7	.35	.37	0	.28
Mean	.38	.25	.13	

Statistically significant differences were not found between single and multiple pollinations in terms of seed set. However, the number of surviving branches in the multiple-pollination treatment was small, only 11.

Sixty-one percent of the acorns collected germinated within 2 months after sowing. Germinating acorns were also significantly heavier than those that failed to germinate.

Differences among replications (trees) were evident in all analyses. We conclude that breeding parents should be carefully chosen for reproductive ability when controlled pollinating oaks.

Controlled pollination in white oak proved feasible in this study. In fact, controlled pollination resulted in higher seed set and sound seed yield, than wind pollination on all trees investigated. Bagging with screen wire seemed to protect against weeviling, which was noted only in unshielded acorns.

In the study by Williamson (1966), 65 percent of the acorns on white oaks fell prematurely within the first month after pollination. In our studies very few acorns abscissed by July 3, 1968, which was nearly 2 months after pollination. In fact, abscission occurred in only one of 13 bagged, unpollinated branches before July 3; development in the others appeared normal. Complete abscission had occurred on all bagged, unpollinated branches by the time of the next inspection, August 19. Climatic differences between Williamson's study area and New Haven and genetic differences among trees may account for the contrasting results.

Results from the experiment in Mississippi (table 3) were similar to those from Connecticut. Controlled pollinations yielded a higher seed set (6.5 percent) than wind pollinations (1.3 percent).

Table 3.--Results of controlled and wind pollinations in southern Mississippi, 1968

Item and unit of measure	Controlled pollination tree			Wind pollination tree		
	1	2	Total	1	2	Total
Branches bagged (No.)	21	25	46	62	55	117
Branches setting seed (No.)	6	3	9	0	9	9
Flowers (No.)	162	130	292	402	347	749
Acorns (No.)	16	3	19	0	10	10
Seed set (Pct.)	9.9	3.1	6.5	0	2.9	1.3
Acorns/branch (No.)	0.8	0.1	0.4	0	0.2	0.1

Frequency of sclereids in current year stems increased with tree age. The more mature age classes failed to produce root primordia when subjected to conditions favorable to rooting of juvenile root suckers. It was concluded that the inability to form primordia rather than mechanical restriction of roots by thick-walled cells is the cause of reduced rooting.

Differentiation of root primordia occurred in interfascicular areas of aspen stems in the primary state of growth and associated with rays after secondary growth had occurred. Roots developed from the cambium or primary cambial derivatives in the interfascicular or ray regions.

Literature Cited

1. Breakbane, B. A. 1961. Structure of the plant stem in relation to adventitious rootings. Nature 192: 954-955.

2. Carlson, M. C. 1950. Nodal adventitious roots in willow stems of different ages. Amer. J. Bot. 37: 555-561.

3. Girouard, R. M. 1967a. Initiation and development of adventitious roots in stem cuttings of *Hedera helix*: Anatomical studies of the juvenile growth phase. Can. J. Bot. 45:1877-1881.

4. Girouard, R. M. 1967b. Initiation and development of adventitious roots in stem cuttings of *Hedera helix*: Anatomical studies of the mature growth phase. Can. J. Bot. 45:1883-1886.

5. Mahlstede, J. P., and D. P. Watson. 1952. An anatomical study of adventitious root development in stems of *Vaccinium corymbosum*. Bot. Gaz. 113:279-285.

6. Nanda, K. K., Anand, V. K., and P. Kumar. 1969. Rooting ability of cuttings of forest tree species and its relationship with tissue characteristics, nutrition, and auxin. Proceedings F.A.O., I.U.F.R.O. Second World Consultation on Forest Tree Breeding 2: 1419-1430.

7. Ruggeri, C. 1966. (II) Anatomical research, p. 42-50. *In* A. de Phillippis (ed.). Factors affecting the difficult rooting of cuttings in some poplars. Res. Final Rep. (*Centro di Sperimentazione Agricola E. Forestale*. Rome, Italy and *Instituto di Sperimentazione per la Pioppicoltura*. Casale Monferrato, Italy).

8. Sachs, R. M., Loreti, F., and J. Debie. 1964. Plant rooting studies indicate sclerenchyma tissue not a restricting factor. Calif. Agr. 18(9):4-5.

The difference in seed set between the two locations may be associated with the length of the growing seasons. The time interval from anthesis to collection is 100 days greater in Mississippi than Connecticut. During this extended period the acorns are subject to additional effects of predators (animals, fungi, and insects) and to stress conditions such as drought.

Better seed sets from controlled than wind pollinations at both locations may indicate that controlled pollination is feasible over the entire north-south range of white oak. Yield/pollination was low in both areas, however, and no attempt was made to cross northern with southern sources.

Gibberellin Effect

Pollen germination was depressed by GA_7 in all levels of sucrose. Additionally, neither GA_7 nor sucrose alone increased the rate of germination or tube length. It must be concluded, therefore, that GA_7 does not improve but, rather, impairs the estimate of pollen viability.

Pollen Storage

The average germination of freshly collected pollen was 34 percent. Germination averaged 31 percent for pollen stored 70 days at 23.5 percent RH; that stored at higher humidities failed to germinate. After 295 days in storage at 23.5 percent RH, germination still averaged nearly 20 percent.

The best freeze-drying treatment combination was prefreezing followed by freeze-drying for 10 minutes and storage under vacuum. After 300 days the average germination achieved with this treatment was 9 percent, which compares poorly to 31.5 percent for pollen from the same tree stored at 2° C. and 23.5 percent RH for 295 days.

None of the unpollinated flowers produced acorns and all abscissed before June 15. Thus, there was no evidence of contamination or apomictic behavior. At least one viable acorn was produced by pollinating with year-old pollen (1) stored at 2° C. and 23.5 percent RH, (2) freeze-dried without prefreezing for 10 minutes and stored in nitrogen gas, (3) prefrozen, freeze-dried for 30 minutes and stored in nitrogen gas, (4) prefrozen, freeze-dried for 10 minutes and stored in vacuum, and (5) prefrozen, freeze-dried for 30 minutes and stored in vacuum (table 4). In this *in vivo* test of viability for pollen stored 1 year, the freeze-dried pollen produced higher acorn yields than the pollen stored at 2° C. and 23.5 percent RH. The *in vitro* test predicted the reverse. Though the numbers of pollinations and the seed set were minimal, it was demonstrated that year-old, stored pollen is capable of fertilization. The freeze-drying treatments involving storage in nitrogen appear to be the best and warrant further testing.

Table 4.--Acorns set on white oak flowers pollinated with fresh pollen and with pollen stored under various conditions

Storage conditions	Flowers pollinated	Acorns	Success ratio
	Number	Number	Percent
Not stored (fresh)	152	41	27
2° C., 23.5 percent RH	29	1	3
Freeze-dried 10 min.,			
Nitrogen storage, not prefrozen	38	5	13
Vaccum storage, prefrozen	63	1	2
Freeze-dried 30 min.,			
Nitrogen storage, prefrozen	56	5	9
Vacuum storage, prefrozen	41	1	2

Some abscission of flowers and stalks was noted in all treatments at the time of debagging about 3 weeks after pollination. In the controlled-pollination trials of 1968, very little abscission was observed even 2 months after pollination. Therefore, there may be some year-to-year variation in premature fruit drop.

This is the first known report of successful storage of oak pollen for 1 year. Controlled pollination, again as in 1968, resulted in higher seed set than that commonly reported for wind pollination [e.g., 1 to 5 percent according to Williamson (1966)].

All experiments were exploratory but the results are encouraging. Intraspecific controlled pollination of white oak demonstrated that feasible pollen viability was maintained in storage for 1 year, and pollen viability was assessed by germination on artificial media.

LITERATURE CITED

Ching, Kim K., and Ching, Te May. 1959. Extracting Douglas-fir pollen and effects of gibberellic acid on its germination. Forest Sci. 5(1): 74-80.

Irgens-Moller, H. 1955. Forest-tree genetics research: Quercus L. Econ. Bot. 9: 53-71.

Ness, H. 1918. Hybrids of the live oak and overcup oak. J. Hered. 9: 263-269.

Nygaard, Per. 1969. Studies on the germination of pine pollen (*Pinus mugo*) *in vitro*. I. Growth conditions and effects of pH and temperature on germination, tube growth and respiration. Physiol. Plant. 22: 338-346.

Piatnitsky, S. S. 1960. Evolving new forms of oak by hybridization, pp. 815-818. *In* Fifth World Forest. Congr. Proc. Vol. 2, Moscow, USSR.

Schreiner, E. J., and Duffield, J. W. 1942. Metaxenia in an oak species cross. J. Hered. 33: 97-98.

Sharp, Ward M., and Chisman, Henry H. 1961. Flowering and fruiting in the white oaks. I. Staminate flowering through pollen dispersal. Ecol. 42: 365-372.

Sharp, Ward M., and Sprague, Vance G. 1967. Flowering and fruiting in the white oaks. Pistillate flowering, acorn development, weather, and yields. Ecol. 48: 243-251.

Williamson, M. J. 1966. Premature abscissions and white oak acorn crops. Forest Sci. 12: 19-21.

Wright, J. W. 1953. Summary of tree-breeding experiments by the Northeastern Forest Experiment Station, 1947-50. USDA Forest Serv. Northeastern Forest Expt. Sta. Pap. No. 56, 47 pp.

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